LOUISIANA COASTAL WETLANDS RESTORATION PLAN

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INTRODUCTION

PURPOSE OF THE PLAN

In November 1990, Congress passed and President Bush signed Public Law 101-646, Title III, the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA, Exhibit 1). Two key points explain the value and historic importance of this law.

- The vast wetlands of coastal Louisiana support valuable renewable resources that are of local, state, national, and international significance. Approximately one-third of the nation's fishery landings, which add an estimated $680 million to the State's economy annually (Keithly 1991), are dependent on these wetlands. Additionally, this ecologically rich coastal area is the basis for a major sporting and tourism industry that adds $338 million to the State's economy annually. However, unlike any other state in the union, Louisiana loses over 25 square miles annually of the resource base supporting such industries, as a result of natural and human-induced hydrological, geological, and ecological processes. Nearly one million acres of these nationally important coastal wetlands have been lost in the last 60 years (Dunbar et al. 1992).
- Public concern and the tremendous ecological and economic importance of coastal wetlands to Louisiana prompted the Louisiana Legislature to take action in 1989. Louisiana Act 6 provides a long-term revenue source for coastal restoration that may vary from $5 million to $25 million per year (Louisiana Revised Statutes 49:213 and 49:214). A referendum to protect this funding source through an amendment to the Louisiana constitution passed by a margin of three to one, showing the overwhelming state-wide public support for this measure. This commitment of economic resources provided Congress the impetus and assurance of necessary matching funds to launch a parallel federal initiative to address coastal land loss.

The CWPPRA provides the first national mandate for action. Even more importantly, the Act has initiated the prudent process of reinvesting in restoration a tiny fraction of the billions of dollars that these wetlands provide every year in renewable (fish and wildlife) and non-renewable (oil and gas) resources. The Act directed that a Task Force consisting of representatives of five federal agencies and the State of Louisiana develop a "comprehensive approach to restore and prevent the loss of coastal wetlands in Louisiana."

Section 303(b) of the CWPPRA requires preparation of this comprehensive restoration plan and specifies:

> Such plan shall coordinate and integrate coastal wetlands restoration projects in a manner that will ensure the long-term conservation of the coastal wetlands of Louisiana.

This report responds to that Congressional mandate. The Restoration Plan is a product of communication, coordination, and cooperation not only among the designated participants from the state and federal agencies, but also through the formal, and more often informal, involvement of numerous local government agencies, the academic community, private environmental and business groups, and countless motivated individuals with good ideas.

DISTRIBUTION OF THE PLANNING RESPONSIBILITY

INTERAGENCY PLANNING GROUPS

Section 303(a)(1) of the CWPPRA directs the Secretary of the Army to convene the Louisiana Coastal Wetlands Conservation and Restoration Task Force, to consist of the following members:

- the Secretary of the Army (Chairman)
- the Administrator, Environmental Protection Agency
- the Governor, State of Louisiana
- the Secretary of the Interior
- the Secretary of Agriculture
- the Secretary of Commerce.

The State of Louisiana is a full voting member of the Task Force except for selection of the Priority Project List [Section 303(a)(2)], as stipulated in President Bush's November 29, 1990, signing statement (Exhibit 1). In addition, the State of Louisiana may not serve as a "lead" Task Force member for design and construction of wetlands projects of the Priority Project List (the priority list process is described in Exhibit 3).

In practice, the Task Force members named by the law have delegated their responsibilities to other members of their organizations. For instance, the Secretary of the Army authorized the commander of the Corps' New Orleans District to act in his place as chairman of the Task Force.

To assist it in putting the CWPPRA into action, the Task Force established the Technical Committee and the Planning and Evaluation Subcommittee. Each of these bodies contains the same representation as the Task Force--one member from each of the five Federal agencies and one from the State. The Planning and Evaluation Subcommittee established several working groups to evaluate projects for Priority Project Lists and the restoration plan. The Environmental Work Group was charged with estimating the benefits (in terms of wetlands created, protected, enhanced, or restored) associated with various projects. The Engineering Work Group reviewed project cost estimates for consistency. The Economic Work Group performed the economic analysis which permitted comparison of projects on the basis of their cost effectiveness. The Monitoring Work Group established a standard procedure for monitoring of CWPPRA projects and developed a monitoring cost estimating procedure based on project type.

The core of the plan development process was centered in interdisciplinary basin teams for each of the nine hydrologic basins in the coastal area which reported to the Planning and Evaluation Subcommittee. The nucleus of each team consisted of representatives of the five federal Task Force agencies and the State; these six members made the final decisions on team recommendations. However, team meetings frequently involved additional agency representatives, scientific advisors, and local interests. The basin teams developed the comprehensive restoration plans for the basins. They also have served as the first level of screening for proposed Priority Project List projects.

PUBLIC PARTICIPATION

The Task Force also established a Citizen Participation Group to provide general input from the diverse interests across the coastal zone: local officials, landowners, farmers, sportsmen, commercial fishermen, oil and gas developers, navigation interests, and environmental organizations. The Citizen Participation Group was formed to promote citizen participation and involvement in formulating Priority Project Lists and the restoration plan. The need to incorporate another invaluable resource--the state's scientific community--was also recognized. The Task Force therefore retained the services of a scientific advisor, who selected a team of scientists to work with the basin teams in the preparation of Priority Project Lists and the development of the basin restoration plans.

An evolving public involvement program implemented by the Task Force provides an opportunity for all interested parties to express their concerns and opinions and to submit their ideas concerning the problems facing Louisiana's wetlands. Exhibit 2 presents details of the public involvement in this process to date, as well as an outline of a proposal for the future.

The program has utilized a series of meetings to accomplish several purposes: to identify wetland loss problems throughout the coastal zone; to develop potential solutions to those problems (literally hundreds of ideas were submitted to the Task Force through these meetings--Exhibit 4 provides a list of these proposals); to present and receive comments on the conceptual restoration plans developed for each basin; and to obtain public input on the candidate projects for the Priority Project Lists.

Comments and responses pertaining to the draft version of this report (dated June 1993) are contained in Appendix J.

<u>ADDITIONAL ELEMENTS OF THE CWPPRA</u>

In addition to the development of the restoration plan pursuant to Section 303(b) of the Act, a number of related wetland restoration and protection activities are to be implemented. These include the identification and construction of priority restoration projects, preparation of a wetland conservation plan, and implementation of a feasibility study to consider flow distribution between the Atchafalaya and Mississippi rivers.

PRIORITY PROJECT LISTS

Section 303(a) of the CWPPRA authorizes the construction of wetland protection and restoration projects through the development of Priority Project Lists, to be submitted to the Congress annually. These are lists of projects which provide for the creation, protection, restoration, or enhancement of Louisiana's coastal wetlands, ranked in order of the projects' cost effectiveness. Priority list projects are generally relatively small-scale projects which can be brought to fruition within five years of being named to a Priority Project List. At this level, the act provides for a somewhat limited but effective and rapid response to the problem of coastal wetlands loss in Louisiana.

Reports covering the first three Priority Project Lists were submitted in November of 1991, 1992, and 1993 (Exhibit 3 provides the details of the development and selection of these project lists). The three reports recommended the construction of 48 projects , with a fully funded cost of approximately $123 million. The reports also have identified several projects as deferred, to be constructed in the event one or more of the primary projects cannot be implemented within the five-year limit specified by the CWPPRA. It is estimated that the 48 recommended projects will create or prevent the loss of more than 46,000 acres of wetlands over the next 20 years.

On April 17, 1993, the lead Task Force agencies signed cost-sharing agreements with the Louisiana Department of Natural Resources for 11 priority list projects, the first such agreements to be executed under the CWPPRA. The Task Force has granted construction approval for four of these projects. Contracts were awarded in November 1993 for construction of the Vegetative Plantings demonstration project at Hackberry and the Bayou LaBranche Wetland Creation project.

WETLANDS CONSERVATION PLAN

The Restoration Plan and Priority Project Lists represent the initial elements in solving the Nation's most critical coastal wetland loss problem. Equally important is the need for complementary management actions (i.e., improved regulatory control), because much of Louisiana's coastal wetland loss ultimately results from activities conducted or authorized by government agencies. These management actions are to be addressed through the development of a wetland conservation plan under Section 304 of the CWPPRA. The Secretary of the Army, Administrator of the Environmental Protection Agency, Director of the U.S. Fish and Wildlife Service, and Louisiana Department of Natural Resources are preparing a cooperating agreement to specify agency roles and responsibilities for wetlands conservation plan development. The plan's goal is to achieve no net loss of wetlands in the coastal zone resulting from development activities. The conservation plan will complement the restoration plan presented herein, potentially incorporating regulatory and other measures, incentives, and mitigation to achieve its goal.

RIVER FLOW MODIFICATIONS

In addition to actions specified in Sections 303 and 304 of the CWPPRA, Section 307(b) of the act adds another element to the program by authorizing and directing the Secretary of the Army to "study the feasibility of modifying the operation of existing navigation and flood control projects to allow for an increase in the share of the Mississippi River flows and sediment sent down the Atchafalaya River for purposes of land building and wetlands nourishment." The 307(b) study has not been funded yet, but consistent with the spirit of the CWPPRA, this Restoration Plan includes consideration for flow modifications of the type authorized for study. The plan underscores the urgent need for initiating studies of flow distributions between the Mississippi and Atchafalaya rivers to build and nourish wetlands.

DEVELOPMENT OF THE RESTORATION PLAN

To facilitate the problem identification and plan formulation called for in section 303(b) of the CWPPRA, the Louisiana coastal zone was divided into nine hydrologic basins: Pontchartrain, Breton Sound, Mississippi River Delta, Barataria, Terrebonne, Atchafalaya, Teche/Vermilion, Mermentau, and Calcasieu/Sabine. These basins represent the basic components for initiating plan development. The coastal zone, which includes all or part of 20 Louisiana parishes, and the nine basins are shown in Plate 1.

Scoping meetings held in 1991 were the first stage in the process of identifying coastal wetlands problems and developing basin-by-basin solutions. The process continued with a series of basin plan formulation meetings, held in early 1992. These meetings were intense planning sessions, consisting of four three-day meetings with a two-day followup for each of the four meetings. Coastal wetlands problems and their causes were discussed in detail, and strategies were developed for dealing with those problems on a basin-by-basin basis. These strategies were molded into conceptual plans that continue to serve as a guide in selection and evaluation of projects both for Priority Project Lists and for the Restoration Plan.

During these meetings, many of the ideas submitted in the 1991 scoping meetings were integrated into the conceptual plans. The planning effort has refined the conceptual basin plans over the last year so that, taken together, the basin plans form the restoration plan.

The Louisiana Coastal Wetlands Restoration Plan is presented in six logically structured sections:

- The first is this INTRODUCTION to the preparation of the plan.
- Second is the assessment of the wetlands RESOURCES in coastal Louisiana, including their national, regional and local value.
- Third is the evaluation of the complex natural and man-induced processes that are causing the PROBLEM of wetlands loss, and which if left unabated will have catastrophic consequences.
- Fourth is a review of the SOLUTIONS available to address these problems--the proven as well as the innovative techniques which can be used to create new wetlands and abate wetlands losses.
- Fifth is the PLAN itself, which fits the best short-term and long-term solutions to the varying problems in each of nine hydrologic subbasins across coastal Louisiana.
- Sixth is a specific outline of actions for the IMPLEMENTATION of the plan.

The result of the Task Force's investigations, developed through this combined effort, is the blueprint for coastal restoration presented in this report.

ENVIRONMENTAL SETTING

OVERVIEW

The coastal wetlands and estuaries of Louisiana are one of the world's great ecosystems. For millennia, the Mississippi River has supplied the coast with an immense resource of fresh water, nutrients, and sediment, building a vast expanse of marsh and swamp land. Natural erosional processes have continuously altered these lands. The dynamic interplay of land and water, where new lands are always being built and old lands changed and lost, has produced an environment rich in natural habitats, with an unsurpassed diversity in vegetation, wildlife, and fisheries, and an extraordinary biological productivity.

Encompassing four million acres, Louisiana's coastal marshes and swamps represent over 40 percent of the estuarine wetlands in the contiguous United States and provide 20 percent of the country's annual commercial harvest of fish and shellfish. Millions of people rely directly or indirectly on the marshes for their livelihood and for protection against hurricanes and storms. This land is the heart of the unique Cajun culture, an invaluable cultural heritage whose influence extends far beyond the boundaries of Louisiana. The area is also of enormous economic importance in ways not directly related to wetlands, especially because it produces some 15 percent of the nation's oil and over 20 percent of its natural gas, and because the Mississippi River ranks as the country's most important inland navigational waterway, as well as the access route to one of the largest deep-draft ports in the world.

In the last several decades, however, humans have impacted this ecosystem in many ways, especially by controlling rivers so natural floods no longer build wetlands in the quantities they once did, and by dredging channels that expose freshwater marshes to salt water at an unnatural rate.

As the twentieth century progressed, each year coastal Louisiana lost its wetlands at an increasing rate, reaching about 40 square miles per year in the 1970's. This represented 80 percent of all coastal wetland loss in the United States and constituted an economic cost of about one-half billion dollars per year. Recently the rate has slowed somewhat, but still it exceeds 25 square miles per year. Many signs indicate that if nothing is done, large rates of loss will continue--and in some areas perhaps increase--far into the future. The ultimate economic cost will be in the billions of dollars; beyond that, there will be immeasurable damage to cultural and environmental values.

Any plan to benefit Louisiana's coastal wetlands must include restoration and enhancement of the natural processes that first created this ecosystem. This cannot be achieved without an understanding of the geomorphological processes that have built and changed the coast and formed the resulting landscape, and of the ecological principles that govern its use by living organisms.

DELTA FORMATION AND DETERIORATION

Deltas and rivers, like all natural systems, are continually in a state of change, evolving toward a new set of conditions. Ecologists see the process reflected in plant and animal community succession. It is important to understand this natural

Key Terms

Natural Processes. The forces responsible for shaping our environment are dependent on geothermal energy, solar energy, and movement of air and water, including tides. These forces result in geological and geomorphological transformations, be they due to tectonic, erosional, subsidence, or sedimentary processes.

Sediment Accretion. Wetlands are built by the accumulation of sediment, or sediment accretion. Under natural conditions, rivers reaching the Louisiana coast have periodically overflowed their banks and carried sediment-laden water into areas between river channels. During a flood, the heaviest sediments are dropped on the river bank (at the natural levee), while the finer sediments are transported farther and build mudflats. The vegetation on the levees and mudflats grows, then decays, and much of the decaying organic material accumulates on the land, adding to the buildup of material. The fresh water and nutrients which accompany the sediment are also major resources which are vital to the wetlands.

Subsidence. The compaction of soft sediments deposited by the rivers and vegetation is the most important of many processes which cause the land surface to become lower over time. Additionally, crustal downwarping due to the thick sediment pile deposited by the Mississippi River over millennia is a near-constant land lowering process. Land lowering is termed subsidence. When subsidence (plus the added effect of sea level rise) exceeds sediment accretion, the land is said to experience a sediment deficit. Land with a sediment deficit will gradually become flooded.

Marine Forces. Winds, tides, and currents in the Gulf of Mexico are sources of energy and water which modify the land and which ultimately can turn subsiding wetlands into open lakes and estuaries. Important marine processes include: flooding of the land with salty water during high tides and storms; shore erosion by waves (especially during storm surges); and the transport and redeposition of eroded sediments. In active deltas where sediment accretion is large, marine forces mostly attack the margins. But in the areas where subsidence dominates, the marine forces increasingly penetrate into and change the interior marshes.

adaptability as we seek to manage wetland sustainability. The major sedimentation cycle, delta switching at about 1,000-year intervals, is an example of succession.

Figure 1 illustrates how a delta is built, then abandoned, by the Mississippi River. First, the river extends its channel into open water; when floods overflow the channel, sediment accretion builds land out of the sea as an "active" delta. This continues until the slope of the river is so flat that sediment is not moved efficiently. Then the river channel will shift to a new, more efficient course and build a new delta. These are known as lobes and actually contain many different sublobes and channels (or distributaries) of varying sizes. The delta-switching process has built up what we now know as coastal Louisiana (see Figure 1 of the Executive Summary). When the river switches, the previous delta lobe is considered "abandoned," and begins to degrade through erosional processes, even though some flow may continue down the old distributary.

Nature's Response to Changes in the Deltas.

Each stage in the cycle of delta building and abandonment is characterized by different natural processes and ecological conditions. The slow but continual transformation of coastal Louisiana depends on the balance between fluvial (river) and erosional processes, modified to some extent by the accumulation of organic sediments. These processes are listed in Table 1.

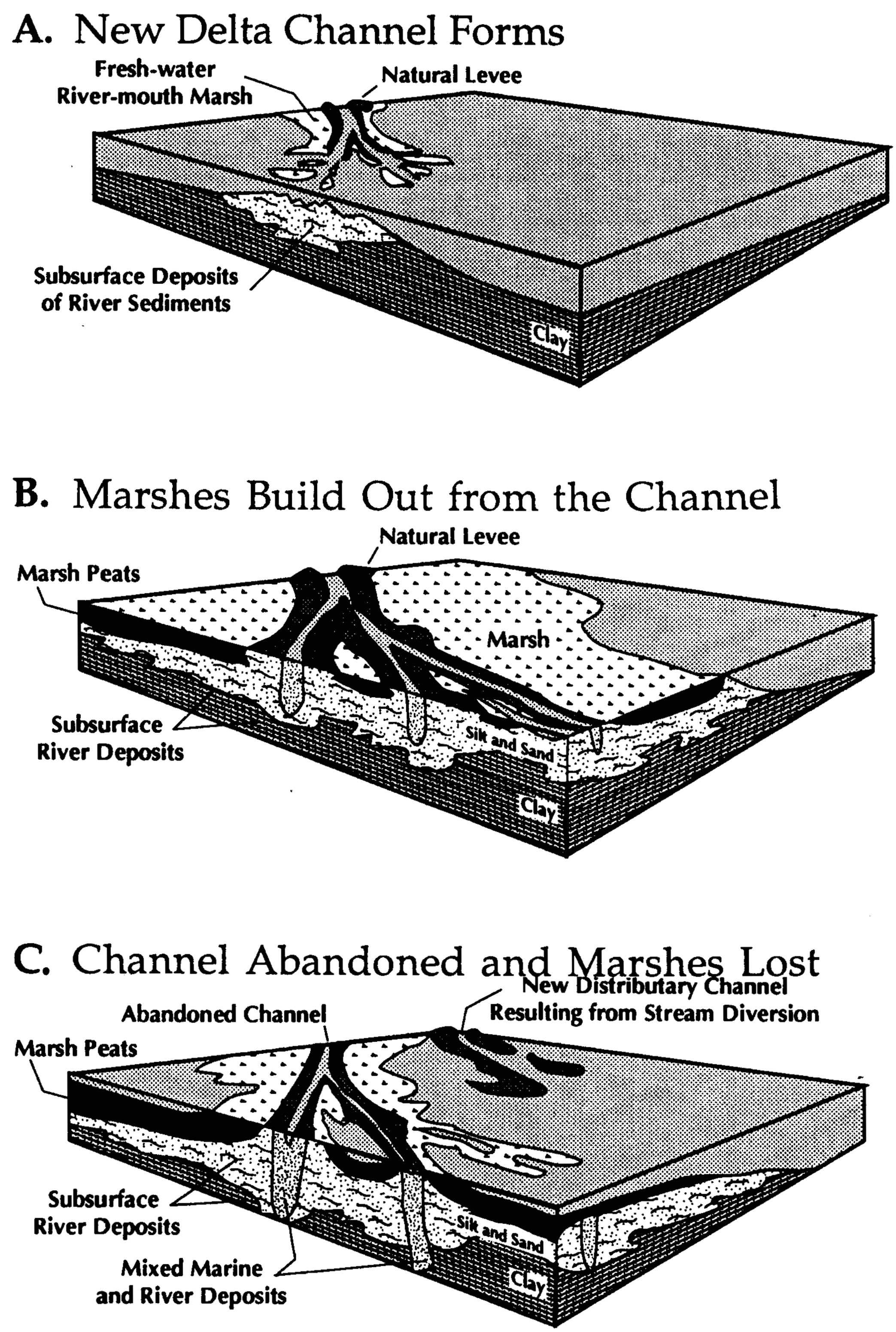


Figure 1. Delta Growth and Abandonment.

Table 1
Geomorphological Processes in the Coastal Zone

Erosional Processes (Land Loss)	Fluvial Processes (Land Building)
subsidence	sedimentation (inorganic)
tidal action	spring floods
storms	delta switching
wave action	freshwater introduction

Erosional processes generally lead to wetland loss, while natural fluvial systems lead to land gain. Each coastal basin is in a different state of succession and can be viewed as fitting on a continuum extending from predominantly erosion-dominated to fluvial-dominated processes. Those basins losing land the fastest primarily are affected by erosional processes. Those gaining land are controlled by fluvial events and are on the other end of the spectrum. A combination of erosional and fluvial processes governs the remainder of the basins.

Prior to European settlement along the Mississippi River, the deltaic plain not only sustained itself above sea level but also gradually increased in area and elevation. This was a product of dominance by various fluvial processes, such as overbank sedimentation during spring flood events, crevassing, channel bifurcation, and delta switching, which overcame the natural subsidence.

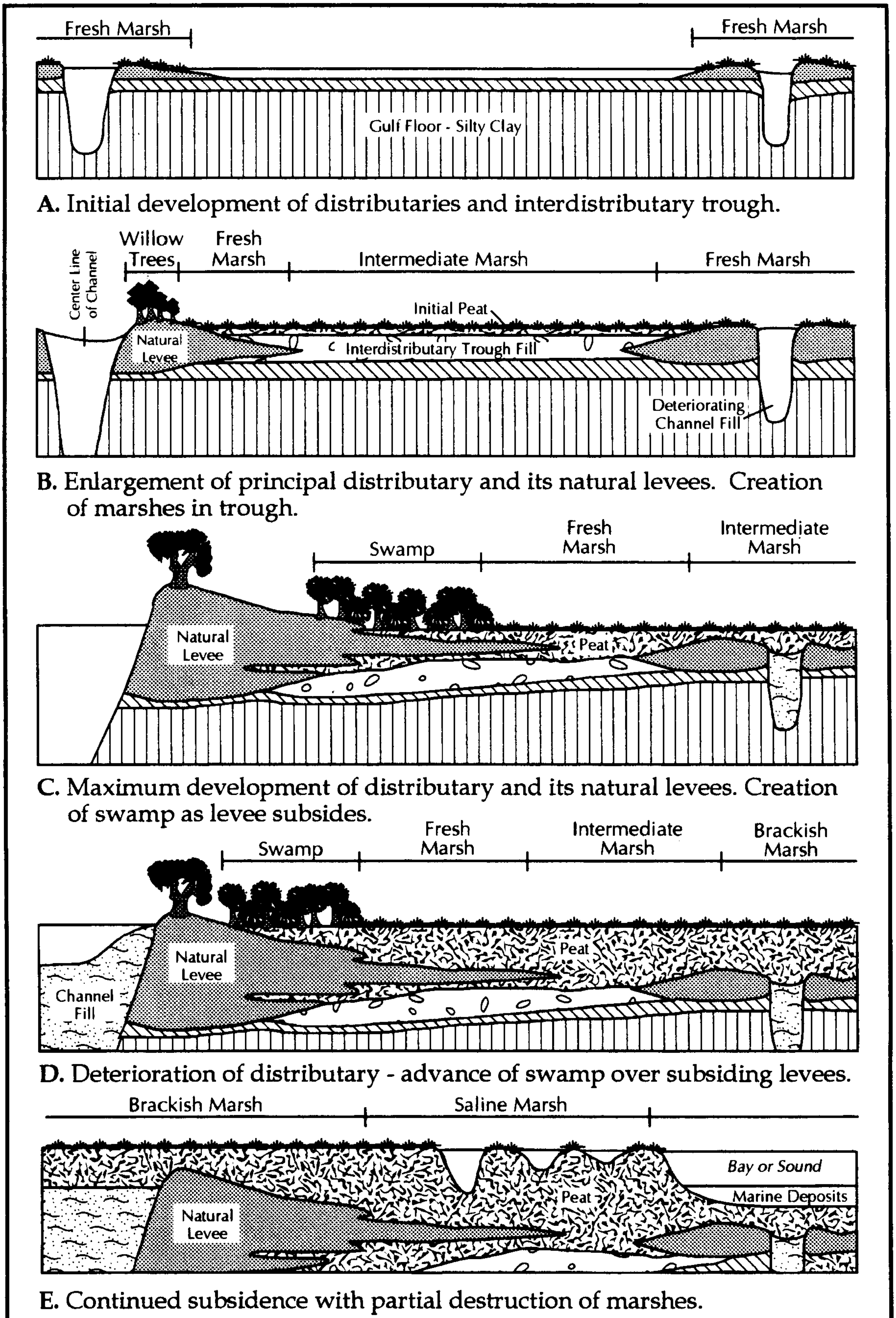
Human actions have tended to curb fluvial land-building processes and favor the dominance of erosional processes. They therefore tipped the balance in the direction of land loss.

Natural System Units and Dominant Processes.

Within coastal Louisiana we recognize three major natural system units: active delta, abandoned delta, and chenier plain. The deltaic plain, which makes up the eastern half of the coastal zone, consists of active and abandoned deltas units. The following sections will discuss the relationship between erosional and fluvial processes and the major ecological conditions within each. Human impacts on these physiographic units are disregarded in the following characterizations.

Deltaic Plain--Active Delta.

In an active delta, the key physical processes are those related to the input of fresh water and mineral-rich sediment. Thus, fluvial processes dominate and control the erosional processes of subsidence, wind-wave and ocean swell erosion, tidal scour, etc. The net result is expansion of the wetland surface over time and creation within the system of extensive freshwater habitats. Figure 2 is an idealized cross section showing the evolution of a delta distributary and adjoining marshes. With time, the delta and associated fluvial channels prograde and fill in the landscape's topographic lows to create vegetated wetlands.



A. Initial development of distributaries and interdistributary trough.

B. Enlargement of principal distributary and its natural levees. Creation of marshes in trough.

C. Maximum development of distributary and its natural levees. Creation of swamp as levee subsides.

D. Deterioration of distributary - advance of swamp over subsiding levees.

E. Continued subsidence with partial destruction of marshes.

Figure 2. Stages in Growth of a Delta and Marshes.

During the building process, the highest land, the coarsest and most stable sediment, and the freshest water are found at the natural levees near the sediment source. Elevations decrease, sediment becomes finer and more organic, and salinities increase away from the stream. Marshes develop between channels on an organic-rich (peaty) soil, while the natural levees support flood-tolerant forests. Just before abandonment, the land is at its greatest extent, still dominated by river processes and fresh water.

Deltaic Plain--Abandoned Delta.

In the abandoned delta, erosion processes dominate fluvial. However, fluvial inputs of fresh water and nutrient-rich sediment, although reduced from when the system was an active delta, lead to the maintenance of large parts of the wetlands. Initially, this maintenance nearly balances the wetland loss processes.

In cases where the production of organic materials is prolific, marshes may maintain themselves above the sea for a long time after abandonment. But the combined effects of reduced fresh water and sediment plus subsidence eventually allow marine impacts to increase. A strong salinity gradient is established from fresh water at the landward end toward the salty water at the Gulf of Mexico end, and vegetation follows this pattern, with fresh marsh inland grading to salt marsh near the gulf. As the marine forces begin to dominate, the shoreline is reworked into sandy headlands and barrier islands, and tidal channels form. The marsh is increasingly eroded or flooded out, and the land opens to form shallow interior lakes and bays (estuaries) that are connected to the sea by the tidal channels. The barrier islands slowly move landward, generally at a lower rate than the outer shoreline of the marshes, so that the estuary is gradually enlarged. Ultimately, the outer coastal marshes are eroded into a series of islands, with the barrier islands separated from the marshes by large, open bays. The estuarine system is eventually replaced by a sound (e.g., Breton Sound). Moreover, the estuary is restricted to small bays within the marshes that have tidal connections to the sound.

Biological productivity is at its peak during the early stages of abandonment, when the landscape changes most rapidly and ecological conditions are particularly diverse. This explains why the most recently abandoned delta lobe, in the area of the Barataria and Terrebonne estuaries, is so productive for commercial fisheries. The fact that productivity can increase as wetlands decrease helps mask the fundamental problem that wetland destruction ultimately will cause a loss in biological and economic value.

Chenier Plain.

West of the complex of abandoned and active deltas is the chenier plain, an area formed by Mississippi River sediments that have been carried westward by currents along the coast and reworked by marine forces into low ridges and intervening wetland swales parallel to the coastline. The shoreline was built outward through mudflat accretion at times when the active delta was near the western edge of the deltaic plain and when fluvial processes dominated, and was eroded back when the delta was to the east and the process balance shifted to the erosion end. The chenier ridges are the remnants of the old, reworked shorelines, and the intervening swales are the old mudflats. The majority of the beach materials are shell and shell fragments. These are derived from the eroded mudflats and from shell organisms on the shallow inner shelf. Ocean swell processes rework the shells into the beach profile.

The interval when the dominant chenier processes change from erosional to fluvial, such as is occurring today, is marked by both progradation and rapid shoreline erosion. The onset of the fluvial phase increases the turbidity within the shallow inner shelf's water column. This affects the productivity of the region's clams and snails, which in turn reduces the quantity of shell material that can be incorporated in the beach.

The chenier plain also contains large inland lakes that were formed after the last glaciation, when the sea level rose and drowned old river valleys. The natural environments of the chenier plain are strongly affected by fresh water from rain and upland runoff. This water is impounded in the flat, low-energy zone behind the chenier ridges, and extensive freshwater marshes have developed on peaty materials around the lakes. Narrow passes connect these inland wetlands to the Gulf of Mexico, and, under natural conditions, tidal influence (and salt water) penetrated a relatively limited area around the passes. The ridges were historically forested, and salt marshes flourished on the seaward side of the cheniers.

BIOLOGICAL ABUNDANCE OF THE WETLANDS

The salinity gradient between inland fresh water and marine salt water is dynamic; it varies over time and space as, for example, winds and tides push salt water inland, or river floods push fresh water seaward. However, under natural conditions the gradient is sufficiently stable that it results in well-defined zones of vegetation roughly parallel to the coast, with salt marshes along the gulf and fresh marshes at the upper ends of the estuaries (Figure 3). Swamp forests occur on slightly higher ground farther inland.

Dominant species in different zones are depicted in Figure 4. Species diversity is greatest in fresh marsh and decreases seaward. Prior to major human impacts, Louisiana's coastal region contained nearly 1 million acres of swamp forest and about 3 million acres of marshes, of which 60 percent were in the deltaic plain and 40 percent were in the chenier plain.

Marshes are an abundant source of food for fish and wildlife--animals that inhabit the wetlands permanently, and an even larger spectrum of animals that use the wetlands seasonally. The food production rivals that of intensively cultivated farms, due in part to the warm and moist climate, the abundance of nutrients, and the substantial energy resulting from water movement. Upon the death of the plants, this production becomes the base of a detrital food chain. Organic debris washes into adjacent lakes and streams, where it supports intense biologic activity. It is here that the detritus accumulates, and where crawfish and oysters proliferate, juvenile fish find food and shelter, and carnivorous fish and birds find an abundant diet.

Figure 5 illustrates the energy and food flows among the inland areas, marshes, the estuaries, and the Gulf of Mexico. The marshes, old distributary channels, tidal channels, and shallow lakes are vital habitats because of their role as nursery grounds for virtually all commercial and sport fish species and wintering grounds at the southern end of the major duck and goose migration corridors. Additionally, the area is a major stopping-off point for migratory song birds and other birds en route from the northeastern United States to Central and South America and back.

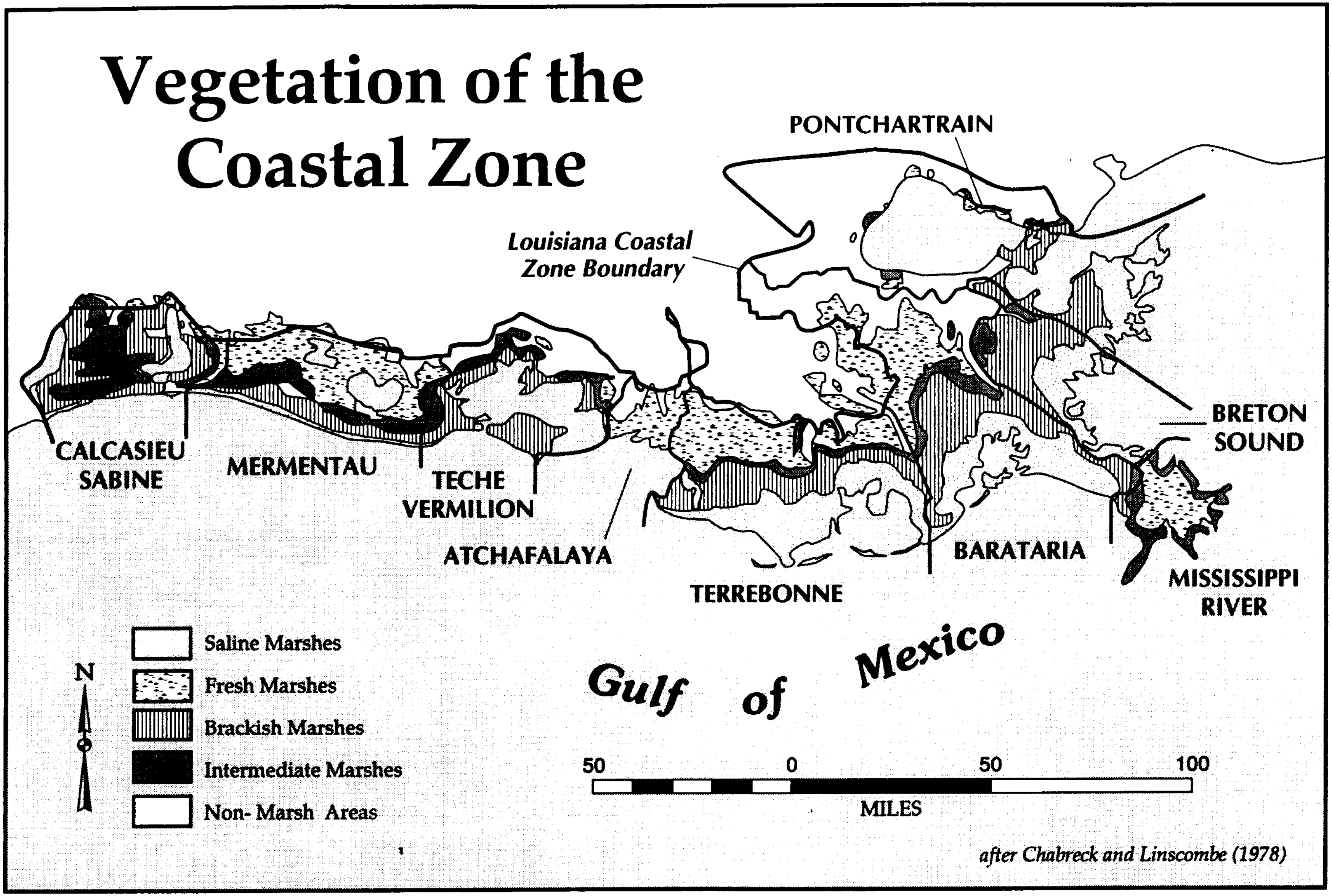


Figure 3. Marsh Types of the Coastal Zone.

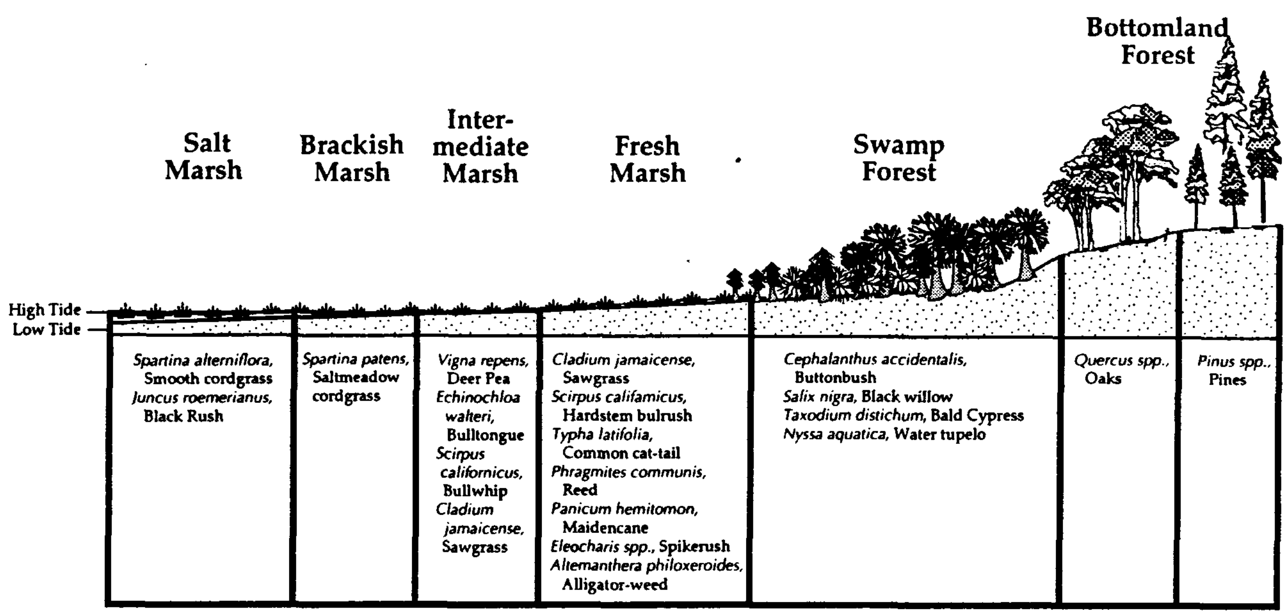


Figure 4. Dominant Plant Species in Different Wetland Types.

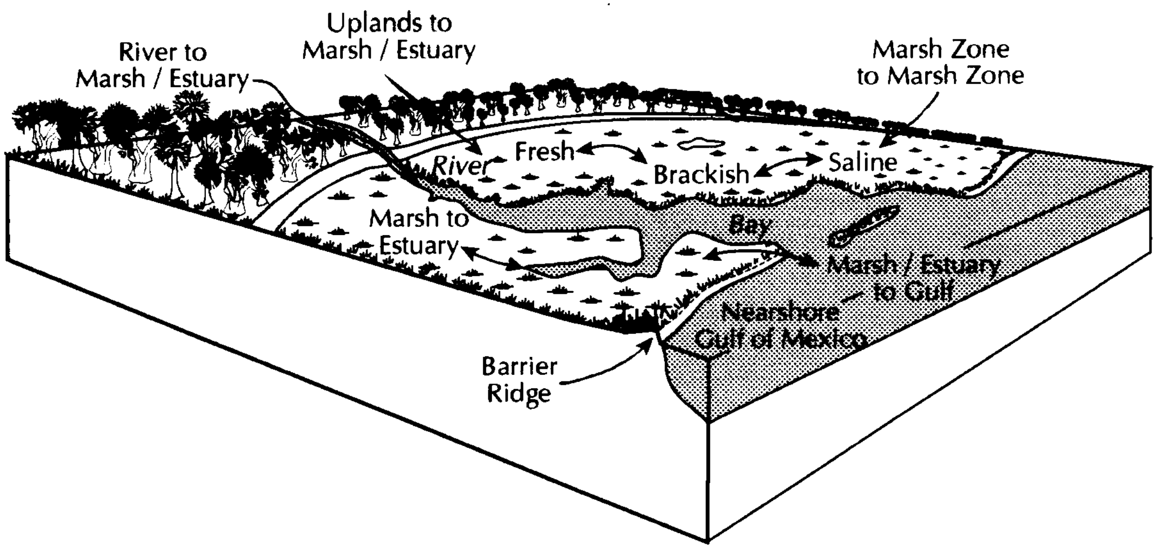


Figure 5. Energy Flow in the Coastal Zone.

Different marsh types support different species; moreover, the fish and wildlife species using the wetlands change substantially over the course of a year, further contributing to the overall complexity and value of the habitat.

THE VALUE OF COASTAL WETLANDS

The economy of southern Louisiana, today as in the past, is closely tied to its geography and geologic history. Following two centuries of sporadic visits by European explorers, settlement began in the early 18th century with the arrival of French colonists. Fertile delta soils deposited by ancient meanders of the Mississippi River eventually fostered a plantation-based agricultural economy that produced indigo, tobacco, sugar cane, cotton, and rice as primary crops. Heavily wooded regions and easy access to water transport also gave rise to timber exports. Economic activity expanded along with greater development and exploitation of the Mississippi River and the access it provided to domestic and foreign markets. Modern development has added manufacturing, service, and resource sectors featuring major ports, oil and gas exploration and refining, chemical production, ship and oil rig construction, tourism, and commercial and recreational fishing. Actions taken to enhance these enterprises, or to protect them from the high intrinsic flood risks of the coastal area and the delta, account for the chief human impacts on the wetlands.

The national wealth and infrastructure created over the nearly three centuries of economic activity in the project area form a context in which to view the relatively minor cost of remediation. More importantly, continuation of some of these activities and continued accrual of related wealth hinges on solution of the wetland loss problem.

The sections that follow describe the economic resources at stake in coastal Louisiana under three general categories: values directly dependent on the marshes and their output; values based on economic activities and infrastructure investments; and values arising from the unique coastal ecosystem and man's social and cultural adaptations to it.

FISH AND WILDLIFE VALUES

The wetlands within the Louisiana coastal area are a natural resource of immense regional and national economic importance. National Marine Fisheries Service statistics for the period 1984-91 show that the commercial fisheries dependent on this habitat contributed an average of 20 percent of the nation's harvest. These marshes also produce more wild furs and hides than any other state in the United States, valued at nearly $20 million annually.

Louisiana fishing ports, which include four of the country's ten largest, produce a catch comparable to that of the entire Atlantic seaboard, and double that of the remaining gulf states. These landings command an annual market value of nearly $1 billion. Important species include shrimp, oyster, blue crab, and menhaden. Combined, these four species account for 98 percent of the annual catch value. Data on shrimp and oyster harvests, when adjusted for unreported landings, indicate that the coastal fisheries supplied 35 to 40 percent of the nation's needs. These catch data, as presented in Table 2, reflect a pro rata assignment of the entire gulf harvest based on the percentage distribution of productive wetlands (see EIS).

Table 2
Gulf of Mexico and Louisiana Coastal Area Estuarine-Dependent Commercial Fisheries Harvest and Value

Species	1983-1990 Average Landings 1/ (Pounds)	Correction Factors for Unreported Landings 2/	1983-1990 Average Corrected Landing (Pounds)	1992 Normalized Price 3/ ($)	1992 Gross Exvessel Value 4/ ($)
Blue Crab	61,740,498	2.00	123,480,996	0.58	71,618,978
Shrimp	247,554,500	2.00	495,109,000	2.17	1,074,386,530
Oyster	21,614,731	1.90	41,067,989	2.61	107,187,451
Menhaden	1,739,444,500	1.00	1,739,444,500	0.05	86,972,225
Croaker	307,383	1.00	307,383	0.58	178,282
Black Drum	7,032,894	1.00	7,032,894	0.44	3,094,473
Red Drum	3,500,956	1.00	3,500,956	1.15	4,026,099
Catfish	5,754,891	1.00	5,754,891	0.60	3,452,935
Flounder	1,473,552	1.00	1,473,552	1.04	1,532,494
King Whiting	669,077	1.00	669,077	0.37	247,558
Mullet	25,011,536	1.00	25,011,536	0.41	10,254,730
Sea Catfish	135,484	1.00	135,484	0.21	28,452
Sea Trout Spot	2,704,407	1.00	2,704,407	1.16	3,137,112
Sea Trout White	516,460	1.00	516,460	0.54	278,888
Sheepshead	3,514,347	1.00	3,514,347	0.23	808,300
Spot	272,907	1.00	272,907	0.29	79,143
Finfish	6,773,194	1.00	6,773,194	0.23	1,557,835
Total Gulf of Mexico	2,128,021,317		2,456,769,573		1,368,841,485
La. Coastal Area 5/	1,361,933,643		1,572,332,527		876,058,551

1/ Source: U.S. Department of Commerce, National Marine Fisheries Service. Published and unpublished data for the years 1983 to 1990.

2/ Correction factors based on information provided by the Louisiana Department of Wildlife and Fisheries.

3/ 1992 Normalized Prices were calculated by escalating the exvessel values of the 1983-1990 catches to March 1992 price levels using the Consumer Price Index.

4/ Based on 1992 normalized prices and the 1983-1990 average corrected landings.

5/ Gulf of Mexico landings allocated to the Louisiana coastal area are based on the relative abundance of estuarine marsh habitat.

The fishery resource also supports a wide range of related businesses such as processing and canning, shipping, wholesale and retail operations, and restaurants. On-water operations are likewise dependent on boat building and repair yards, net and gear manufacturing, ice making, and commercial marinas. Employment data suggest that from 50,000 to 70,000 people are directly engaged in these fisheries and in subsequent processing, wholesaling, and other activities. Because a substantial portion of the fish caught in Louisiana's offshore waters are landed and processed elsewhere, numerous jobs in adjacent gulf states also depend on the continued productivity of this state's wetlands.

Also based in these coastal wetlands is a major recreation industry. Primary leisure activities include fishing, hunting, boating, picnicking, birding, and camping. A study completed in 1984 for the LSU Center for Wetland Resources estimates that the 180,000 licensed saltwater sports fishermen in the state annually spend $181 million on fishing and have nearly $1 billion invested in boats, gear, camps, and other equipment. The study estimates the total annual economic impact of sport fishing-related expenditures at over half a billion dollars. A later analysis produced by the Sport Fishing Institute put the total economic impact at nearly $900 million for the year 1985.

Located at the southern end of the Mississippi and Central Flyways, Louisiana marshes are the overwintering site for nearly 70 percent of the ducks and geese migrating along that route. The economic value of the hunting provided by the flyway exceeds $10 million annually. Waterfowl hunting and recreational fishing supported by Louisiana wetlands exceed 3 million annual user days.

Various methods have been proposed that attempt to capture all of the mentioned marketable outputs, as well as non-marketable but nonetheless valuable outputs, in a dollar-based expression of wetland value. Methods which include the value of the wetlands as a processor of urban and agricultural waste products, its storm buffering effects, surrogate values based on captured energy, and existence value to non-users produce per-acre values ranging from a few hundred dollars to $40,000 or more, in addition to the value of real estate and mineral rights. Using the upper end of this range, the current loss rate exceeds half a billion dollars a year. When confined to the more easily documented fish and wildlife outputs that make up most of the value at the low end of the range, the numbers are still impressive. If wetland losses are permitted to continue unabated, by the year 2040 wildlife and fishery harvests will decline by about $220 million annually compared to present levels. Most of these losses will be made up by foreign supplies. Real estate assets valued at $240 million also will be lost.

CAPITAL ASSETS AND INFRASTRUCTURE

Human alteration of the environment and the physical landscape in Louisiana began with the early French colonists, who settled along the natural levees of the Mississippi River and its tributaries. The site selected for the settlement of New Orleans was chosen for its strategic location near the Bayou St. John Portage, a primary trading route to Mobile. Because the site tended toward periodic flooding, settlers began constructing a levee system shortly after the founding of the town. From that time to this, the economic history of the region continues to be largely a story of enterprises carried on under the protection of public and private flood control works.

The French settlers who recognized potential in the site picked for New Orleans chose well. Located at the gateway to the entire Mississippi Valley, it today marks the center of the nation's largest deep-draft port complex. Facilities located between the mouth of the Mississippi River and Baton Rouge annually handle cargoes of over 230 million tons, valued in excess of $30 billion. These cargoes, which exceed in volume the traffic of the entire West Coast of the United States, include about 25 percent of this nation's exported commodities and 24 percent of its grain shipments. The ports along this deep-draft segment of the river serve as transshipment terminals for these cargoes and for other shallow-draft movements utilizing the vast network of inland waterways formed by the Mississippi River, its tributaries, and connecting streams. The value of the transfer service provided by these facilities is estimated at about $400 million a year.

Three other deep-draft ports are located in coastal Louisiana: Lake Charles, Morgan City, and Port Fourchon. The Port of Lake Charles serves an important chemical and refining center, handling about 30 million tons of high value cargoes annually. Morgan City and Port Fourchon primarily function as construction and service centers for the offshore oil and gas industry. Additionally, many commercial fishermen operate out of these ports.

The Gulf Intracoastal Waterway, a critical link in the country's shallow-draft transportation system, also traverses the project area wetlands. Freight carried on this waterway has averaged about 70 million tons annually in recent years. Total transportation savings to the nation generated by this system during the period 1940-90 are equivalent to $936 billion in today's terms. In addition to the national and international trade carried on over area waterways, these channels, along with numerous smaller feeder streams and canals, also serve as a vital transportation asset of the oil and gas activities centered in the state's coastal region and in the Gulf of Mexico. All told, the coastal navigation features threatened by wetland loss represent nearly 3,000 miles of deep- and shallow-draft channels built and maintained with billions of dollars of public investments.

Other transportation facilities in the project area include: mainline railroads; Federal interstate highways; numerous other U.S., state, and parish highways; an extensive oil and gas pipeline network; and commercial airports. The Southern Pacific, Illinois Central, and Amtrak lines provide service to most of the area. Service is extended via spur lines along the alluvial ridges as far south as the GIWW and along the Mississippi River below New Orleans. The primary east-west highway routes are Interstates 10 and 12 and U.S. Highways 90 and 190. Major north-south routes include Interstates 49, 55, and 59, and U.S. Highways 51, 61, and 165.

Pipelines are the primary carriers of petroleum products imported, produced, and refined in the coastal zone. Over 14,000 miles of onshore and 2,000 miles of offshore pipelines are located in the area. Also located in this vulnerable region is the Louisiana Offshore Oil Port, Inc., which began operations in 1981. This $700 million dollar offloading facility supplies 15 percent of the country's imported oil, moved from ships unloaded at a floating terminal 18 miles south of Grand Isle through pipelines to storage caverns in the Clovelly salt dome. Oil is then transferred from the salt caverns to a system of seven pipelines serving refineries along the gulf coast and in the Midwest. Other terminals in the area contribute another 5 percent to the supplies of imported crude oil, for a state total of about 20 percent of U.S. imports.

In addition to being a major importing center, Louisiana is a primary producer of energy resources. The state provides about 15 percent of the nation's crude petroleum and over 20 percent of its natural gas supplies. The combined value of these two products averaged $16 billion annually for the 1986-91 period. Nearly 90 percent of this output is extracted from the coastal area and adjacent offshore waters. Abundant supplies of crude petroleum and natural gas, fresh process water, and nearby water transportation account for the concentration of refining and petrochemical manufacturing facilities located in the project area, primarily along the Mississippi and Calcasieu rivers. These industries, which rank Louisiana as the nation's third largest chemical producer, ship commodities valued at nearly $50 billion annually. There were over 90,000 refining and refining-related jobs in the state during 1992.

Tied to these and other economic activities are major population centers and their related public and private infrastructure, valued at well over $100 billion. These are protected from the destructive river and tidal flood events characteristic of low-lying regions by an extensive system of levees and other protective works which, when completed, will represent an investment of nearly $12 billion. Estimates of storm and flood damage that would have occurred without this protection suggest the flood risk faced by the 2.1 million people living in the region's coastal communities: works already in place have prevented $111 billion in losses since 1927.

The marshes surrounding the economic landscape described above--the cities, towns, businesses, industries, transportation corridors, etc.--are an integral design consideration for the flood control features on which the entire region depends. Continued substantial loss of wetlands will require that levees and other structures be enlarged or relocated in order to maintain current levels of protection. Activities and features located outside of existing lines of protection will likewise be impacted. Highways, ports, waterways, railroads, pipelines, and other utilities will need to be relocated, or will experience major escalations in maintenance costs. Businesses, residences, camps, schools, and other structures in the coastal area will also need to be protected or relocated at great expense. To the extent that wetland loss can be offset, particularly in specific, critical locations, many or most of these economic losses can be avoided.

CULTURAL VALUES AND TOURISM

Coastal Louisiana can claim a rich mixture of cultural backgrounds and community histories. Initially settled by the French and later ceded to the Spanish, the region boasts a lengthy and diverse roll of ethnic groups who have made important contributions to Louisiana, both before and after its admission to the United States in 1812. Native Americans, Anglo-Americans, African-Americans, the Acadians, Italians, Irish, Germans, French, Spanish, Canary Islanders, Dalmatians, Chinese, Filipinos, and others are among the major ethnically distinct populations who now reside in the coastal zone. The earliest of these settlers made their livings, often in the face of adversity, as planters, farmers, fishermen, trappers, loggers, moss gatherers, and other occupations keyed to the rich natural environment. Out of this heritage arose the social and cultural systems that set the area apart from the rest of the nation. The languages, the customs, the cuisines, and a view of life unlike any other continue to distinguish the area.

Tourism, a major component of the local economy, is inextricably linked to the unique regional characteristics which evolved from past and present interactions of coastal Louisiana populations and their wetland environment. State tourism officials estimate the expenditures, payroll, and tax receipts in the 20-parish project area at slightly over $4 billion in 1991, producing about 61,000 jobs. Visitors to New Orleans alone number 11 to 12 million persons annually. The loss of these coastal societies and their cultural, culinary, and esthetic identities which will accompany continued wetland disappearance will clearly impact this sector of the regional economy. Beyond that, something of great value to the nation may be lost as well--the unique cultural heritage of south Louisiana.

SUMMARY

The economic assets and activities described in this section have been impacted for several decades by coastal processes set in motion by man and nature. Some of the effects, such as the gradual decline of fishery productivity and failure of related businesses, are subtle and difficult to detect in the short term. Others can be dramatic, such as failure of a levee overstressed because adjacent protective wetlands are lost. Without decisive action, however, current losses will accelerate and other losses will be felt as newly critical areas are affected. As the shoreline approaches mainline flood protection levees, communities will incur substantial costs for upgrading protection and for relocations. Unprotected features will require costly additional works. Some features will doubtless be lost altogether.

Local resources available to address the problem are limited. The 1980-90 decade was marked by substantial turmoil in one of the region's primary economic sectors, the oil and gas industry. Consolidations, down sizing, and transfer of operations to other states or foreign locations resulted in significant unemployment and out-migration. As detailed in the socioeconomic discussions contained in the EIS, the population is not projected to soon return to the levels generated during the peak of the oil and petrochemical industry expansions.

Maturation of these industries and lower regional birth rates also forecast long-term declining employment. As these industries and the payrolls they support decline, so will the Louisiana tax base.

As the cost of flood protection rises and overall economic activity declines, scarce local tax revenues will be diverted from other deserving community needs. Tax burdens in general will increase; business operations will grow more costly and less competitive. Average incomes will fall and quality of life will suffer. Most of the conditions characteristic of long-term regional decline will exist.

There are also serious implications from the national point of view. For example, the Federal government is the primary provider of navigation and flood control works. As land loss encroaches on channels and levees located in the coastal zone, Federally built facilities will grow more costly to maintain or will require additional investment to function properly. Long-term viability of some presently threatened communities is also an issue that carries wide ranging risks for disaster relief funding and other Federal emergency programs. Threats to the several large wildlife refuges in the project area will similarly strain the budgets of the natural resource agencies.

Indirect effects will also be felt at the national level. This region is a primary producer of energy and many other basic materials on which the U.S. economy depends. Economical supplies of these products and their efficient movement through coastal ports and waterways are matters that involve much more than Louisiana alone.

The problem will never be less expensive to solve than it is now; on the other hand, the cost of inaction will grow exponentially.

THE PROBLEM: LOSS OF COASTAL WETLANDS

INTRODUCTION

Recognizing that extremely valuable resources are at risk, it is important to determine what the problems impacting the resources are and to what extent they are human induced. The primary causes of wetland loss in coastal Louisiana have been understood for some time; they include subsidence, global sea level rise, sediment deprivation, and hydrologic alteration (Boesch 1982; Mendelssohn et al. 1983, Titus 1986, Turner and Cahoon 1987, Day and Templet 1989, Duffy and Clark 1989). Subsidence and global sea level rise have combined to subject wetland plant communities to relative sea level rise (RSLR) rates that exceed half an inch per year in parts of the Louisiana coast (Hatton et al. 1983, Baumann et al. 1984). Rapid submergence and local penetration of marine processes into the freshwater interior of Louisiana's coastal estuaries are secondary effects, resulting from the interplay of these factors, that impose stresses on these wetland plant communities (Mendelssohn and McKee 1989, Nyman et al. 1993).

These stresses reduce plant productivity and compromise the inherent ability of most wetland vegetation to withstand submergence by adding sufficient organic matter to the substrate to maintain surface elevation within the intertidal or intermittently flooded zone (Mitsch and Gosselink 1986). A variety of more local impacts, associated with canal dredging, faulting, ponding, hurricanes, herbivory, and erosion by waves and currents, affect stressed marshes--far more severely than healthy ones--and can act as the "last straw" that gives rise to dramatic "hot spots" of loss (Leibowitz and Hill 1987).

Coastal Louisiana has been extensively altered by human activity. Each of the primary causes of land loss has a natural and man-induced component. Subsidence, for example, occurs naturally in the wetlands built by the Mississippi River as a consequence of geologic downwarping and compaction of a sediment column with a high component of water, gas, and organic materials (Kolb and van Lopik 1958, McGinnis et al. 1991). However, subsidence also may be significantly affected by local drainage efforts that reduce the water content of the upper few feet of the soil profile (Harrison and Kollmorgen 1947), by placement of levees and other structures that load the surface (Kolb and van Lopik 1958), or by removal of minerals (e.g., oil, gas, or sulphur) from near-surface deposits.

Similarly, sediment deprivation in a marsh can be a natural consequence of the switching and change in dominance of the various distributaries of the Mississippi River (Coleman and Gagliano 1964), but it also is affected by development of continuous river levee systems that prevent overbank flooding and crevasse development (Kesel 1989) or promote loss of sediment into deep waters overlying the continental slope (Viosca 1928). Finally, hydrologic alterations can occur as a natural consequence of the breakup of barrier island systems at the mouths of estuaries (Penland and Boyd 1981), abandonment of distributary channels, or the development of tidal drainage networks (Tye and Costers 1986). However, the viability of coastal wetlands also is affected by thousands of miles of dredged channels and associated levees that alter hydrology, sedimentation, and salinity regimes (Scaife et al. 1983, Swenson and Turner 1987).

The basin plans included in the appendices of this report provide an overview of the complexity of this system. The remainder of this section is devoted to a review of the research findings critical to the restoration process.

HISTORICAL PERSPECTIVE

More than 4 million acres of the coastal wetlands built by the Mississippi River survived into the 20th Century. Nearly one million of these acres have been converted to open water in the last 60 years alone (Dunbar et al. 1992). It is critical to clearly identify the processes that have caused the most damage in the past to determine whether they are still causing destruction and to prioritize restoration efforts to stop or offset the most serious loss-producing processes.

Much coastal wetland loss in Louisiana, as in other maritime states, accompanied canal, railroad, and highway building, and development of drainage systems for agricultural, industrial, and residential purposes. In the first two decades of the 20th century over 200,000 acres were leveed and put under pump to create agricultural and suburban lands (Harrison and Kollmorgen 1947). Pumping of the organic soils caused rapid subsidence within the leveed areas and many areas, with the exception of some suburban districts adjacent to New Orleans, underwent conversion to open water once the pumps stopped or storms breached the levees.

Unique to Louisiana is the connection between current land loss and the evolution of a comprehensive levee system along the Mississippi River and the damming of distributaries like the Atchafalaya River, Bayou Plaquemine, Bayou Manchac, Bayou Lafourche, and several others south of New Orleans. The confining of the Mississippi River to a small part of its original flood plain and to a single course was initiated to provide flood control in the last century. Efforts to improve navigation resulted in the extension and stabilization of the mouth as a jettied channel to the edge of the continental shelf (Humphreys and Abbot 1861). Sediment supply to river flanking marshes was decreased, but continued to occur through crevasses or high-water levee breaks (Millis 1894).

The disastrous 1927 flood galvanized the Nation and provided impetus for a massive federal effort to raise and reinforce levees for comprehensive flood control (Elliott 1932). Crevassing was effectively stopped and control over the river tightened. Construction of the Old River Control Structure was completed in 1963 to stop the capture of the Mississippi by the Atchafalaya (Fisk 1952) and distribute the combined flows of the Red and Mississippi Rivers so that 70 percent flowed down the Mississippi and 30 percent flowed down the Atchafalaya. Revetments constructed along the Mississippi River and dams built on the Missouri and other large tributaries in the 1950's have affected the amount of sediment reaching the Gulf of Mexico (Meade and Parker 1985, Keown et al. 1986, Kesel 1987).

The suspended sediment load from the Mississippi River drainage system that helped build these wetlands apparently declined in the mid-1950's following a long-term drought and the construction mentioned above (Meade and Parker 1985). Measurements of bed materials also show a shift to finer grained sediment in the active delta during the 20th century (Keown et al. 1981). However, land clearing for agriculture and urban expansion has undoubtedly contributed to increased sediment loading in the river over the last 200 years. These changes, coupled with the elimination of direct input to the wetlands through crevasses, levee breaks, and delta lobe construction, have influenced sediment supply rates to the coastal wetlands.

Development of projects within the coastal basins themselves accelerated once river flooding was controlled. Large navigation channels were constructed and enlarged between 1920 and 1970. The Gulf Intracoastal Waterway joined and incorporated several smaller canals running parallel to, but considerably inland of, the coast. In addition, large channels perpendicular to the coast were built to connect inland ports located along the GIWW with the Gulf of Mexico. These connect the fresh interior marshes with the gulf and provide efficient conduits for freshwater drainage, and for sea water to move inland across natural subbasin boundaries (Wang 1987). Such channels have promoted the invasion of marine processes into freshwater areas previously isolated from them.

Pertinent information on the major navigation channels that transit the Louisiana coastal zone can be found in Exhibit 6 of this report. A high percentage of the banks of these waterways are unstable and were left unprotected during the construction process. As a result, bank erosion has caused many of the channels to grow far beyond the authorized width (Johnson and Gosselink 1982). The Mississippi River Gulf Outlet (MRGO), a channel completed east of New Orleans in 1968, is now as much as 2,000 feet wide, nearly three times its original width of 750 feet.

The dredging of smaller channels for drilling rig access and pipeline installation proliferated in the coastal wetlands of Louisiana during the oil and gas exploration and development boom of the 1950's, 1960's, and 1970's (Lindstedt et al. 1991). Where onshore fields were developed, the marsh was broken up by dense canal networks. Offshore fields also caused destruction as pipeline canals were dredged through the marshes and barrier islands to connect with onshore processing facilities. By 1978, more than six percent of Louisiana's coastal wetlands had been directly converted to open water or spoil through canal dredging alone (Baumann and Turner 1990). Indirect losses are estimated to be considerably greater than this (Cowan and Turner 1987).

Pursuant to the Coastal Zone Management Act of 1972 and subsequent State legislation, a state-administered Coastal Zone Management Program (CZMP) became operational in Louisiana in 1980. This began a new era of public interest and involvement in the way coastal wetland areas were managed and developed. Data presented in Table 3 reflect federal permitting in coastal Louisiana, of which CZMP permits are a subset. Over the period of this record, the number of public notices advertising work proposed in coastal wetlands declined and the acreage of wetlands permitted for dredging and filling decreased by approximately 50 percent.

The decline in public notices and permitted dredge and fill acreage resulted, in part, from a general economic downturn and increased use of general permits. However, these decreases also reflect the heightened public concern and enhanced regulatory efforts through federal and state permitting programs. An important regulatory development has been the increased use of directional drilling by the petroleum industry. This allows exploration of new sites from existing canals or reduced canal excavation to reach drill sites. The increased cooperation between the oil and gas industry and regulatory agencies and the eventual development of a state Conservation Plan will help to ensure that wetlands restored at public expense will not be destroyed later by permitted activities.

Table 3
Acreage Permitted for Development [1]

Year	Number of Public Notices	Area Permitted for Dredge and Fill (acres)
1982	1,645	1,476
1983	1,341	1,413
1984	1,517	962
1985	1,606	2,362
1986	1,138	925
1987	1,138	339
1988	974	402
1989	983	988
1990	1,271	721

[1] Hartman et al. 1993.

The potential for restoration has inspired a great deal of applied scientific study directed at quantifying and categorizing land loss processes. Much new insight has emerged in the past five years, largely as a consequence of research sponsored by the agencies that now make up the CWPPRA Task Force; some of that research is ongoing. The results of this work, together with project monitoring findings, form a credible basis for continued improvement in the design of coastal restoration projects.

CHARACTERIZATION OF WETLANDS LOSS

REGIONAL LAND LOSS

The rates at which different parts of the coastal plain are sinking have been related to the thickness of sediment deposited during the last 8,000 years, which varies across the coastal zone. This sediment has the potential to lose volume by dewatering, degassing, and compaction (Penland et al. 1991). During the last glaciation, about 20,000 years ago, when sea level was about 400 feet lower than it is today, the ancestral Mississippi eroded a deep valley into the underlying Pleistocene surface across what is now the coastal zone. When sea level began to rise, the valley was gradually filled with sediment, until about 5,000 years ago when sedimentation spilled out of the valley across the deltaic plain. Consequently, some parts of the deltaic plain are underlain by a massive thickness of Holocene sediment of more than 400 feet. The Holocene layer gradually thickens seaward (Frazier 1967). Slow seaward growth of the chenier plain on the western end of the state has resulted in a much thinner wedge (generally less than 40 feet) of recent deposits over the Pleistocene (Gould and McFarlan 1959).

The rate of sinking and compaction of organic soils and the varied history of sediment deposition across the coastal zone means that RSLR also varies. RSLR estimates include 0.09 inches per year for regional sea level rise in the Gulf of Mexico (Gornitz et al. 1982), and in Louisiana range from a high of 0.51 inches per year in the Atchafalaya and Mississippi deltas to 0.24 inches per year in the chenier plain (Ramsey and Moslow 1987). However, other factors can affect RSLR in local areas. Basin sediment can move downward along fault lines. There are hundreds of "growth faults" in coastal Louisiana, some of which cause displacement at the land surface. The downthrown side of these faults is seaward, and unless sediment deposition counteracts this displacement, land loss rates may increase on this side of the fault, which is thought to be true in the Barataria basin south of Empire.

The gulf shoreline of Louisiana retreats an average of 13.8 feet per year (U.S. Geological Survey 1988). However, some sections prograde as much as 11.2 feet per year on average, while other sections retreat at mean rates that are as high as 50.2 feet per year. Shoreline movement is not a steady process; accelerated erosion occurs during and after the passage of major cold fronts, tropical storms, and hurricanes (Dingler and Reiss 1991). Field measurements have documented 65 to 100 feet of coastal erosion during a single 3- to 4-day storm. These major storms produce a low-relief barrier landscape (Penland et al. 1988, 1990). Erosion along gulf and bay shorelines has resulted in a 55 percent decrease in the total area of Louisiana's barrier islands, and a great deal of lateral and inland migration, between 1880 and 1988. Isles Dernieres, in the Terrebonne basin, has the highest rate of coastal erosion of any Louisiana barrier system. Over the last 100 years the gulf shoreline of these islands has retreated northward a distance of 5,390 feet

Hurricane Andrew struck the Terrebonne and Barataria barrier islands in 1992, causing extensive erosion and breaching. Beaches were eroded more than 130 feet in two days, and some islands were reduced in area by 30 percent (Stone et al. 1993, van Heerden et al. 1993). The destabilized condition of the barrier islands, combined with the winter storms of 1992-1993, further accelerated the erosion problem (U.S. Geological Survey 1992).

Patterns of land loss between the 1930's and 1983 have been mapped coast wide (Britsch and May 1987), and these maps provide a clear indication that many other "hot spots" of loss exist. For most of these sites the cause of loss is so compounded that it defies any simple explanation (Leibowitz and Hill 1987). While land has been lost along gulf and bay shorelines, far more has disappeared in interior marshes many miles inland of the coast (Turner and Rao 1987), as ponds have formed, expanded, and coalesced into larger water bodies (Fisk et al. 1936, Reed 1991).

WETLAND LOSS AS A FUNCTION OF PLANT MORTALITY

It is important to identify the actual mechanisms through which processes such as submergence and the invasion of marine influences affect different plant communities. Effective measures to reverse coastal land loss must affect plant communities, in their root zone, in such a way as to promote healthy growth and reproduction, plant succession, or revegetation of denuded surfaces.

Sedimentation and the Accretion Deficit.

A positive difference between RSLR (Penland and Ramsey 1991) and the rate of marsh accretion (DeLaune et al. 1978, Baumann et al. 1984, Ritchie and McHenry 1990) implies that sedimentation is not keeping pace with submergence. Accretion deficits in excess of 0.1 inch per year result over time in a lowering of the elevation of affected wetland surfaces relative to a fixed datum (Baumann et al. 1984, Nyman et al. 1993). Even a minute accretion deficit could quickly influence flooding duration in Louisiana coastal marshes, which are seldom more than 1 foot above mean sea level (Chabreck 1970). Marsh water-level data from a deteriorating salt marsh near Cocodrie in the Terrebonne basin, for example, show that while high and low tides occurred daily, the marsh surface drained infrequently and for short periods such that it remained flooded for over 90 percent of an 11-day period of record (Cahoon 1992).

Vertical accretion of wetland soils depends on soil formation from sedimentary material of two types: mineral sand, silts, and clays brought in by flood waters or winds; and living and dead organic matter produced locally by the plants. In Louisiana (Nyman et al. 1990, 1991), organic matter accumulation is frequently more important than mineral sediment input to vertical accretion, except during initial phases of delta lobe building (van Heerden and Roberts 1988). Increased rates of root production, as opposed to above-ground shoot production, appear to be an adaptation to increased flooding in salt marsh cordgrass (*Spartina alterniflora*) and wiregrass (*S. patens*) that can increase the organic component of soil formation (Good et al. 1982). Another unique but poorly understood adaptation occurs when the living root mat of some fresh marshes actually detaches from the more mineral substrate and persists for long periods in a floating condition (Russell 1942). However, such adaptations can only occur if conditions are favorable for continued plant growth.

Pezeshki et al. (1992) showed that plants from all Louisiana coastal marsh types respond positively to experimental additions of mineral sediment and suggests that a certain minimal level of mineral sediment input may be required to maintain productivity. The minimal amount of mineral matter required each year by fresh marsh communities is about half of that necessary for brackish species and less than 20 percent of that needed by the salt marsh community (Nyman and DeLaune 1992). Because overbank flooding from the Mississippi has been eliminated, most of this material is derived from the limited return of Mississippi River discharge back into coastal estuaries via tidal passes, from the Atchafalaya sediment plume, and from bay bottom sediment reworked and distributed by tidal currents. Although the mineral matter may contribute from 50 to 90 percent of the dry weight of a Louisiana marsh soil, this denser material typically occupies from 2 to 7 percent of the soil volume, most of which is actually pore space within a matrix of living and dead plant roots (Nyman et al. 1990).

It is important to recognize that surface elevation in Louisiana marshes is controlled far more by soil volume than by its composition and that the formation of soil mass and structure is largely regulated in place by the plants themselves. Accretion deficits in Louisiana coastal marshes are caused primarily by inadequate organic matter accumulation (Nyman et al. 1993). The organic matter content of the soils supporting fresh, brackish, and salt marsh communities, in contrast to the mineral content, is similar. Inadequate organic matter accumulation results from a shift in the balance between plant production of organic mass, particularly below ground, that adds to the soil organic matter stock, and removal via conversion to carbon dioxide and other gases through decomposition. Any environmental change that lowers productivity or increases the rate of organic matter removal increases the vertical accretion deficit.

Decomposition is more vigorous in the fresh marsh than in the salt marsh and is slowest in the brackish marsh (Smith et al. 1983). As a result, to add enough organic matter to the marsh substrate to maintain position with respect to RSLR, fresh marsh plants must contribute about twice the amount of organic matter each year to the substrate than is true for brackish marshes, and the salt marshes fall in the middle (Nyman et al. 1990). Processes other than decomposition also can remove organic matter and may be locally important. These include lateral erosion of wetland margins due to waves and currents (Gagliano and Wicker 1989), deep burns of marshes during drought periods, and the direct consumption of below-ground root material by nutria, muskrats, and geese that can occur at times when population pressures are severe (O'Neill 1949).

An "eat-out" is a condition that occurs in the marsh when muskrats or nutria have populated an area to the extent of completely consuming the existing vegetation, including the root system which binds the organic soils (O'Neill 1949). Eatouts can be divided into 3 stages: initial, secondary, and final. Recovery of vegetation is dependent on the presence of other stressors, but is not well understood. During the 1970's and 1980's, much greater recognition of wetlands loss led some researchers to conclude that peak populations of muskrats during the 1940's and nutria during the 1960's likely played a major role in the breakup of some interior brackish marshes in coastal Louisiana.

At a Nutria and Muskrat Management Symposium held in October 1992, it was demonstrated that nutria and muskrat herbivory (particularly nutria) has produced substantial adverse economic and environmental impacts. Researchers with the Louisiana Department of Wildlife and Fisheries, United States Fish and Wildlife Service, and Louisiana State University (LSU) indicated that the impact of nutria herbivory is likely having a very significant detrimental effect on coastal vegetation (Conference Summary 1992. Proc. Nutria and Muskrat Management Symposium). These effects are thought to be particularly significant in marshes already stressed by submergence.

Submergence, Salinity, and Sulfide Effects on Plant Productivity.

While all wetland plants are adapted to grow in flooded soils, prolonged flooding negatively affects the productivity of many Louisiana swamp, brackish marsh, and salt marsh species to varying degrees. Plants must use more energy to obtain nutrients and respire toxins when the oxygen content of the soils drops because of prolonged flooding (Gosselink et al. 1977, DeLaune et al. 1979). Most existing information is available for salt (*Spartina alterniflora*) and brackish (*S. patens*) marsh species (Kirby and Gosselink 1976, Hopkinson et al. 1978, Mendelssohn et al. 1981, DeLaune et al. 1983, Mendelssohn and McKee 1988, Nyman et al. 1993) and swamp tree species (Kozlowski and Pallardy 1979, Pezeshki and Chambers 1985, 1986). Less information is available on fresh marsh species, but the negative response to flooding appears much less severe (Crawford and Tyler 1969, McKee and Mendelssohn 1989).

Sudden increases in salinity in waters flooding fresh marshes can result in vegetative die-back (Pezeshki et al. 1987). Brackish and salt marshes contain salt tolerant plant species with salt-excreting organs to make them better able to adjust to salinity increases (Mendelssohn and Marcellus 1976). Salt tolerant plant communities have encroached into historically fresh and intermediate marsh zones in many of the inland reaches of Louisiana's estuarine basins over the past 50 years (Chabreck and Linscombe 1982).

Increased salinity levels are often an important factor contributing to fresh marsh loss in areas adjacent to deep navigation channels or in impounded areas flooded by storm-driven seawater. It appears that sulfate, another constituent of seawater, may be at least as important as the salt itself in inducing toxicity in fresh marshes and reducing productivity in brackish and saline marshes when prolonged flooding results in oxygen-depleted soils. Such conditions can result in significant soil accumulation of free hydrogen sulfide (DeLaune et al. 1983) as well as root oxygen deficiencies (Mendelssohn et al. 1981). These factors can reduce nutrient uptake (Howes et al. 1986), growth, and productivity (Mendelssohn and McKee 1988). The iron associated with mineral sediment found in greater abundance in brackish and salt marsh soils can precipitate sulfides and reduce their concentrations below toxic levels for these marshes (Buresh et al. 1980).

When fresh marsh is killed by the toxic effects of salt or sulfide, it will be converted to open water if succession to salt marsh species is unsuccessful. This may happen if the soil surface elevation drops below the lower limit at which more salt- and sulfide-tolerant plants can live (Sasser 1977), if the mineral content of the soil is insufficient to support these species (Nyman and Delaune 1991), or if the soil is lost to erosion because of the lack of vegetation.

When the plants of any marsh type die, for any reason, the subsequent rapid decomposition of the root mass can result in a reduction in soil strength and a substantial collapse of the soil volume. Such collapses have been observed to result in a soil volume decrease that leads to a surface lowering of up to four inches. For marshes experiencing a RSLR about 0.5 inches per year, the amount of organic matter required to be returned to the soil each year just to maintain elevation begins to approach the limits for annual below-ground plant production (Nyman et al. 1993). Hydrologic changes by humans or nature that affect the sedimentation regime, freshwater supply or depth, and duration of flooding experienced by a marsh plant community influence its ability to flourish in a subsiding landscape (Stevenson et al. 1986, Reed 1991). Those effects may be manifested in the succession of one plant community to another or, alternatively, in the conversion of land to open water.

MAGNITUDE OF THE PROBLEM: LAND LOSS NUMBERS

Two parallel mapping efforts have been undertaken to characterize and quantify land loss on Louisiana's coastal plain by the USACE (Dunbar et al. 1992) and by the FWS and Louisiana Department of Natural Resources (FWS/LDNR). The USACE data set is complete for the entire coastal zone and provides land loss information for four time intervals (1931-33 to 1956-58, 1956-58 to 1974; 1974 to 1983; and 1983 to 1990). It is mapped at a resolution of 1:62,500, the scale of standard 15-minute topographic quadrangle maps. The results of this study are published in Dunbar et al. (1992). The FWS/LDNR effort has recently been completed, covering the time periods of 1956-1978 and 1978-1990. It provides habitat as well as land-to-water change information mapped at a resolution of 1:24,000, the scale of a standard 7.5-minute topographic quadrangle map. This mapping covers changes that have occurred since 1956, when the first comprehensive habitat map was prepared (Wicker et al. 1981).

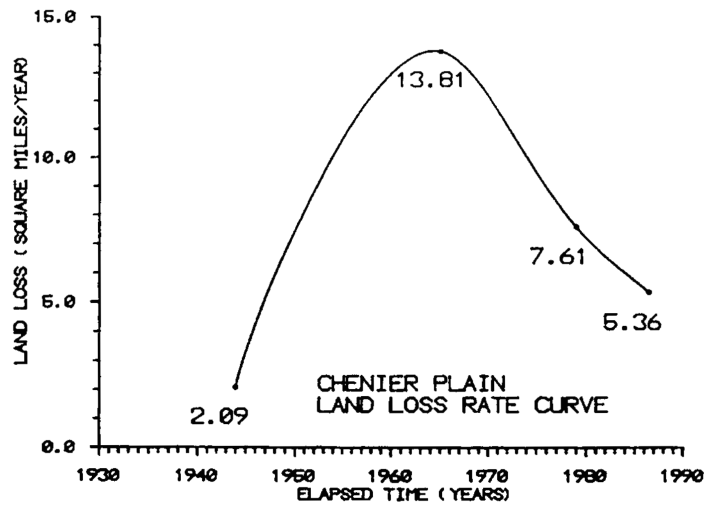
The USACE data set is used for the following discussion because it has been published for the entire coastal zone, dates back to 1932, and recently has been aggregated by the nine basins used to analyze the Louisiana coast (Dunbar et al. 1992). The USACE researchers looked for land loss in 8,511 square miles (5,447,000 acres) of lands identified in an 18,000-square-mile coastal project area, much of which is open water. About 70 percent of this land lies in the delta plain, while the remainder constitutes the chenier plain. It should be noted that a significant portion of the area mapped is not actually wetland but includes developed levee ridges and areas ringed by levees within forced drainage districts. In addition, it is important to note that the USACE methodology measures gross land loss rather than net change in any interval. Open water that is converted to land, as in the Atchafalaya Delta, is not registered as a gain, for example.

The Dunbar et al. (1992) study deserves careful scrutiny because it dates back far enough to tell us much about man's role in accelerating land loss. The 1932 imagery provides a bench mark of conditions prior to most of the major local alterations that humans have made within the coastal plain. Mean annual loss rates, based on an average value over the time period of each data set, are shown in Figure 6 for the coastal plain as a whole, and for the delta plain and chenier plains separately.

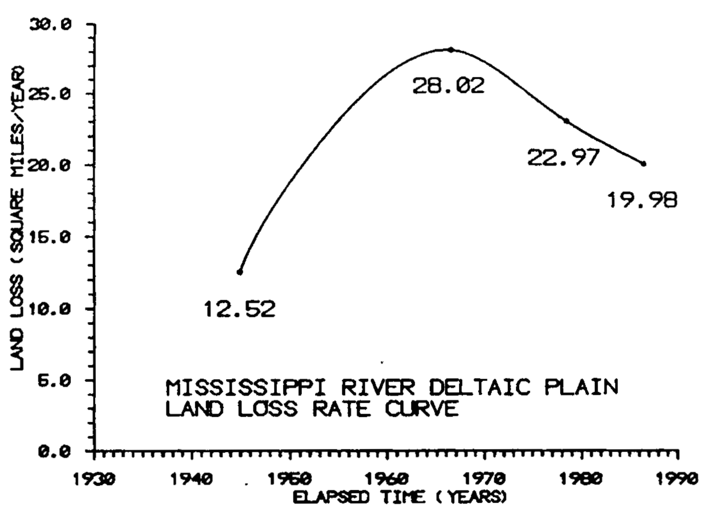
These curves show that land loss increased for the coastal plain during the period between the early 1930's and mid-1970's, rising from 14.6 square miles per year (9,000 ac/yr), prior to the late 1950's, to an extreme value of about 42 square miles per year (27,000 ac/yr). Annual loss had dropped by 1990 to 25 square miles (16,000 ac/yr). Five square miles of loss occur each year in the chenier plain, while the delta plain loses about 20 square miles annually. Aggregate land loss for the entire coastal plain totalled nearly a million acres during the 60 years of record, at an average loss rate of about 27 square miles per year (17,000 ac/yr). Two important points emerge from these data. First, it is apparent that the land loss rate has dropped coastwide over the past two decades. Second, earlier projections of accelerating land loss have not been realized (Gagliano et al. 1981).

Current land loss rates of approximately 25 square miles per year, though still very high, are far lower than earlier extrapolations projecting that annual losses would approach 60 square miles annually by the 1990's. This information challenges an earlier assumption implicit in those projections. That assumption is that land loss is self compounding and perpetuating. Rather, it can now be concluded that much land loss occurred relatively quickly in response to within-basin alterations occurring in the 1950's, 1960's, and 1970's, but the effect of these impacts has tapered off rather than grown over time.

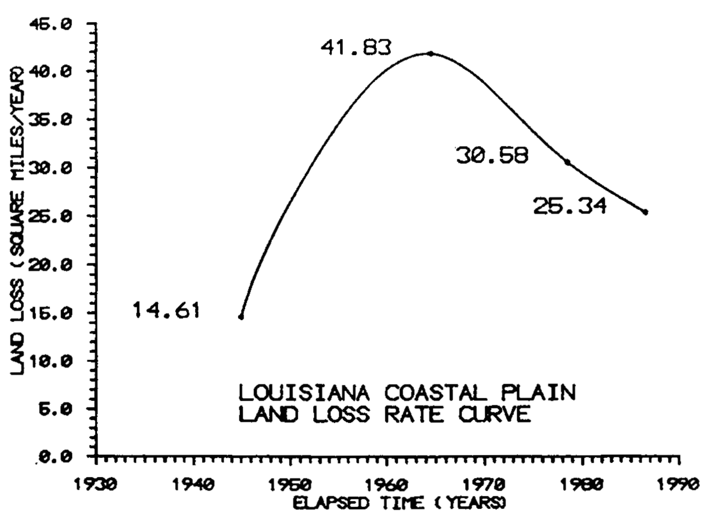
The USACE data set has been broken out along the natural hydrologic basin boundaries used by the Task Force for planning. Time histories of annual land loss for each of the basins are shown in Figure 7. It is apparent that some of the loss curves are more peaked than others. This is most pronounced in the Calcasieu-Sabine basin, where the peak can be taken to represent very rapid loss associated with the compounding impacts of a major navigation project and a devastating hurricane occurring within this time step. In the Breton Sound and Teche-Vermilion basins, a flatter curve may indicate the more gradual effects of shoreline erosion, sediment deprivation, increased marine influences, and subsidence.



a. Curve expressed in square miles per year



a. Curve expressed in square miles per year



a. Curve expressed in square miles per year

Figure 6. Louisiana Coastal Land Loss Rates by Region.

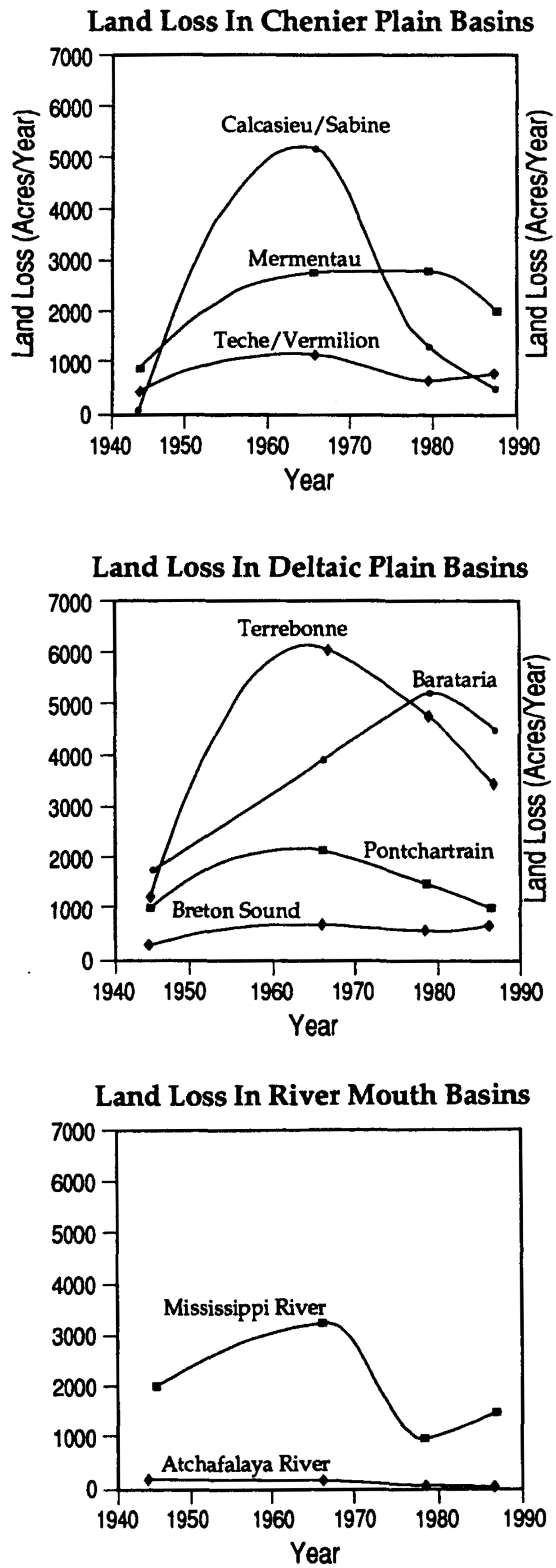


Figure 7. Louisiana Coastal Land Loss Rates by Basin.

From the planning perspective, such comparisons can be useful in allocating restoration resources. They provide at least a qualitative basis for partitioning the recorded and, more importantly, ongoing land loss between local, within-basin alterations and those of a more regional nature, associated with the underlying geology, subsidence, and sediment supply.

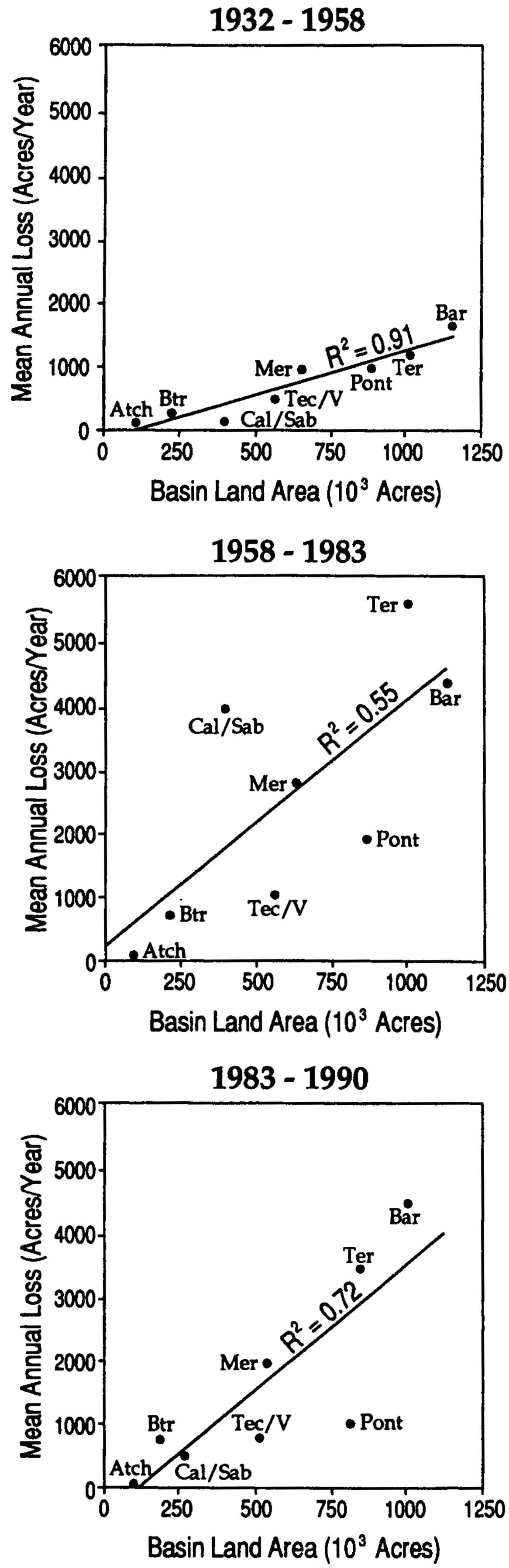
BACKGROUND LOSS

One way to separate out various factors affecting land loss rates is to use the loss data from the first interval (1932-58) as recommended by Dunbar et al. (1992) to provide an estimate of "background" loss. It is important to recognize that this background differs significantly from "natural" loss because it includes the regional impacts of management of the lower Mississippi River and its distributaries. This management began long before the 1930's, but was systematized with the authorization of the Mississippi River and Tributaries project in 1928, and evolved rapidly through the 1940's and 1950's. Canal dredging and road building, however, did far less damage to the interior hydrology of the basins prior to 1958. About 40 percent of the canals present in 1978 were dredged prior to 1958 (Turner and Cahoon 1987). Conversely, most of the disastrous land loss, associated with the wave of failed agricultural reclamations, was already complete by 1932 (Harrison and Kollmorgen 1947).

Background land loss, within the subsiding Louisiana coastal plain largely cut off from its fluvial supply of mineral sediments, is expected to be at least loosely correlated with the initial land area of each basin. Coastal basins with large initial land areas have more to lose. Sediment to maintain existing wetlands must be derived from the erosion of other lands within the system or generated in place by wetland organic production. A plot of mean annual loss rates against basin land area during the background period (Figure 8) shows a positive correlation between basin land area and mean annual background land loss. This analysis is continued for two additional periods. The 1958-74 and 1974-83 data are considered together, and the 1983-90 interval is evaluated separately. The 1958-83 period brackets the time during which most internal basin alterations occurred.

Projecting cumulative background loss rates to the present for each of the basins and comparing these projections with the actual record provides an estimate of "excess" loss for each basin for the 58-year record. The Mississippi and Atchafalaya river mouth basins have experienced cumulative losses within 10 percent of the loss predicted from the 1932-58 background rates. Excess loss for the other basins ranges from a low of 31 percent for the Pontchartrain Basin to a high of 93 percent for the Calcasieu-Sabine Basin. The Terrebonne and Mermentau Basins each experienced cumulative excess loss of about 60 percent, while the remainder of the basins are in the 40-50 percent range. Coastwide, of the approximately 1 million acres that have been lost over the past 60 years, 51 percent falls into the "excess" category. The chenier plain has experienced proportionally more excess loss (70 percent) than has the delta plain (42 percent).

Despite a geological history of dynamic land building and land loss, the magnitude of current land loss in the coastal zone of Louisiana is a relatively recent phenomenon. These high rates of loss are primarily confined to the past 60 years--the period during which the lower Mississippi River was under human control and land building was brought to a halt. It also is a time during which the hydraulic



Atch = Atchafalaya Basin Bar = Barataria Basin Btr = Breton Basin
Cal/Sab = Calcasieu/Sabine Basin Mer = Mermentau Basin Pont = Pontchartrain Basin
Tec/V = Teche/Vermilion Basin Ter = Terrebonne Basin

Figure 8. Land Loss vs. Basin Area by Time Period.

- There can be drawbacks to regional-scale projects which work with natural processes, because so much human activity is presently dependent on the modifications which man has made to the natural ecosystem. Thus, while natural sediment diversions are by far the lowest direct-cost technique for creating new marshes, such projects may incur significant secondary costs because of conflicts in the areas from which the river water is taken (e.g., navigation channels) and in the areas where the diversion would put the water and sediment (e.g., areas which may contain commercial shellfish beds). These are issues to be recognized and addressed in project implementation.

- Developing the important large-scale projects, while resolving potential conflicts, will require completion of detailed feasibility studies.

- The design of all types of projects, large and small, will be improved over time as reliable information is gained from three sources: the monitoring of restoration projects already in place or funded for construction; the use of CWPPRA projects to demonstrate new techniques for wetlands restoration; and research being conducted outside of the CWPPRA.

- There are situations in which the ability to apply ideal solutions is severely limited. An example is the Calcasieu/Sabine Basin, where the natural hydrologic system has limited sediment resources with which to overcome the problems created by the alterations to which it has been subjected.

This introduction to project types makes clear that there is no one "solution" to the wetlands loss problem in coastal Louisiana; the urgency of the coastwide problems requires that restoration work move forward on many tracks at once. The remainder of this section briefly describes the wetland restoration techniques which were given primary consideration in the CWPPRA planning process, including both proven methods (most of which are already being used within the first three priority lists) and some of the exciting new ideas which are conceptual at this time.

For the purposes of discussion, the various techniques have been subdivided into two groups: projects which result in the creation of new productive, sustainable wetlands; and projects which enhance or protect existing wetlands. A concluding discussion briefly reviews additional project types that address significant but unique natural problems.

ADVANTAGES OF PROMOTING NATURAL PROCESSES IN COASTAL LOUISIANA

An emphasis of CWPPRA projects is to increase natural wetlands-building processes by increased sedimentation, and by reestablishing the natural flows of water and sediment which sustain wetlands health. These are the processes which created the valuable resources which now need protection. This approach has a number of advantages.

1. The forces of nature will be used beneficially. This can result in large gains from a relatively small expenditure of effort, thus lower direct costs, especially for maintenance; refer to the text for a discussion of secondary costs.

2. The resulting environment will consist of landforms, ecosystems, and productivity which are determined and maintained by the natural flows of energy and materials, and which therefore approximate the environment which has provided such a natural bounty to the nation. Among other consequences, this means the ecosystem will support natural species diversity and thus, in time, the benefits of restoration will be determined by natural processes more than by human management decisions. (Note that species distributions may be different from those observed at present.)

3. The approach provides for substantial gain in new wetlands, and maintenance of existing wetlands, not simply a reduction in rates of loss. Indeed, this approach recognizes that some changes and losses are inevitable, and aims to work with such changes.

CREATION OF PRODUCTIVE, SUSTAINABLE WETLANDS

Creation and restoration projects are efforts which build new wetlands acres or which build up the land elevation of deteriorated wetlands. These are the projects which must be successful in order to offset wetlands losses and replace unavoidable losses with new coastal wetlands resources; consequently they are particularly critical to the long-term success of any restoration effort.

Two important examples of creation projects were identified at the beginning of this section: diversion of sediment-laden river water into shallow open water, and the beneficial disposal of dredged materials. These examples illustrate the components of a typical creation project.

- Creation projects begin with a source of sediment. Natural sediment can come from a river, a tidal channel, or longshore currents. Sediments can be produced by human action through dredging to cut or maintain navigation channels or through dredging specifically for the purpose of wetlands creation.

- The sediment must be moved to a location where it can build wetlands. In some cases, this is done entirely by nature (as by a longshore current), but commonly it is done by relocating a natural process, as by building a structure to divert river flows, or by gapping a spoil bank so that water in a channel can move into a marsh by overland flow. Where the sediment source is artificial, the transportation process usually requires an energy-intensive human action such as the pumping of dredged material through a pipeline.

- Finally, the sediment must accumulate in open water until the elevation of the solid bottom is raised at least several inches above the water level, or it must accrete on an already emergent area. Accumulation can result from natural processes, or from modifications to those processes; an example is building structures which slow flow so that more sediments drop out. Direct deposition by human activity is also possible, as by spraying of dredged material onto a wetland from a specially-equipped barge, a technique which can build up the marsh surface while enhancing the existing plants (Cahoon and Cowan 1988).

Combining the many sediment sources, transportation mechanisms, and accumulation processes leads to a wide array of creation project types. Describing each combination in detail is beyond the scope of this report; however, some additional information is provided below, to assist readers in understanding subsequent discussions (including those in the basin plans found in Appendices A through I).

SEDIMENT DIVERSIONS

Sediment diversions restore fluvial processes in the wetland environment. Most typically, a levee is cut (and sometimes stabilized) so that some portion of river flow can move into the wetlands on the opposite side of the levee. In contrast to freshwater diversions, which carry only a dilute load of clay material (see subsequent discussion), sediment diversions are focused on capturing flows which are laden with the inorganic sediments most effective in building new land. Consequently, they also divert large quantities of river water. While this fresh water can benefit wetlands by decreasing salinity in the area which receives the outflow, the primary purpose of a sediment diversion is to build new land by mimicking the natural delta-building and wetland maintenance processes.

To date, sediment diversion projects constructed in coastal Louisiana are on a small scale; most involve cutting of crevasses in the natural levees of the Mississippi Delta. One major project, the West Bay Sediment Diversion, was included on the CWPPRA first Priority Project List. It is clear that additional projects are needed, at least some of which must operate on an unprecedented scale. Recent calculations which suggest that the available sediment supply in the Mississippi and Atchafalaya rivers is potentially sufficient to maintain all existing wetlands in the Deltaic Plain (Templet and Meyer-Arendt 1988, Suhayda et al. 1992, Van Heerden 1993).

Because of the scale at which future sediment diversions may operate, and in recognition of possible constraints to such projects (as noted at the beginning of this section), it is evident that detailed feasibility studies will be needed to evaluate how best to rebuild the Mississippi Delta. Beyond issues associated with any particular project, these studies must determine the upper limit to the amount of water and sediment which can be diverted from the Mississippi River system without significantly affecting navigation channel maintenance, municipal and industrial water supplies, and other aspects of human activity, such as commercial and recreational fishing. They also must consider the relative cost-effectiveness of sediment diversions using the Mississippi River, the Atchafalaya River, Bayou

LaFourche, and other distributaries; and areas where sediment accumulation would produce the greatest benefit.

SEDIMENT DREDGING

The Corps of Engineers dredges more than 80 million cubic yards per year in coastal Louisiana during channel maintenance operations. In addition, petroleum and natural gas access canals are dredged periodically, and new canals continue to be excavated, although at a far lower rate than occurred in the past. The volume of material moved by this process each year is similar to what is thought to be required to maintain all of Louisiana's coastal wetlands on an annual basis (Suhayda et al. 1992). Thus, the potential exists for a large number of wetland creation and maintenance projects to make use of material routinely dredged.

Dedicated dredging is that which is done explicitly for the purpose of wetlands creation or restoration. Two CWPPRA priority list projects presently underway in Atchafalaya Bay involve mining material in existing disposal sites or river and bay bottoms and placing it in degraded wetlands. A constraint to dedicated dredging projects is the transportation cost if the point of sediment need is distant from a material borrow site. Demonstration projects can be considered to test techniques which would reduce costs of transportation (as well as dredging and placement costs).

Other concepts which are under active consideration include the use of high-density slurries, which substantially reduce capital and energy costs per unit of material moved (Suhayda et al. 1992), and the use of abandoned oil and gas pipelines. Conceptually, these innovations offer the potential for dedicated dredging to have regional-scale benefits. Recent proposals have expanded the concept of sediment dredging to include innovative sources, such as byproducts of human activities; one example now under study is the use of bauxite mill tailings ("red mud").

SEDIMENT CAPTURE PROJECTS

There are two recognized types of small-scale projects which capture natural sediments: terracing and trapping/inducing. These techniques can be most effective where a dominant one-directional current carries a high load of suspended sediment. Sediment inducers are capable of being applied in conditions where multi-directional currents are present. Structures are built to slow the current, or make the flow less turbulent, and thereby promote sediment deposition. Structure types include:

- terraces built by dredging a bay bottom, so that a network of emergent land is built in shallow open water (this also serves to protect the nearby marshes);

- fences, including those built with recycled Christmas trees, which work best in a low-energy environment; and

- inducers, subsurface features which reduce turbulence (not yet tried, and potentially including anything from artificial reefs to artificial submerged vegetation).

Monitoring of sediment capture projects is an important tool to determine the effectiveness of this technique, and to improve project designs.

ENHANCEMENT AND PROTECTION OF EXISTING WETLANDS

Projects in the "enhance and protect" category act to reduce existing or future losses of wetlands, especially where such losses have been accelerated because of human activity. Descriptions defining two such projects were given at the beginning of this section, one involving hydrologic restoration and the other erosion protection. Although many different enhancement and protection techniques are available, a broad distinction can be made between projects which are directed at natural landforms and those which deal with the human-influenced landscape.

Most natural landforms--such as barrier islands, natural levees, and shorelines--have a positive influence on wetlands. They may promote processes which are important to marsh nourishment, such as retention of sediment-laden fresh water; or they may provide natural protection against tidal forces, wave erosion, and other processes which are a common direct cause of wetlands loss. Loss of these landforms can result from the normal deterioration of an abandoned delta or from human activity; in either case, projects which restore the landform can prolong the life of adjacent wetlands. Such projects usually include some degree of protection to or rebuilding of the landform; this can involve as simple a project as revegetation, or an engineered solution using dredged or other materials.

Many human-built landforms--such as navigation channels, oil and gas canals, and flood control levees--have the potential to adversely impact wetlands by modifying natural processes, especially flows of fresh water, salt water, sediment, and nutrients. Projects typically are directed at restoring some attributes of the natural hydrology, or otherwise improving hydrologic conditions, as the following examples illustrate.

- The natural introduction of fresh water is important to maintenance of healthy wetlands systems, but is often blocked by flood control levees. Freshwater diversions and outfall management are project types which provide a positive response to this problem by restoring the fluvial processes which are important to the estuarine ecosystem.

- An adverse effect of some man-made structures (levees, roads, spoil banks) is to block natural flows, or to provide a direct pathway for freshwater drainage or saltwater intrusion. The term "hydrologic restoration" is used to refer to projects which promote a more natural hydrology by eliminating the unnatural blockages and blocking the unnatural drainages.

- Finally, situations exist where water is already impounded in a wetland, or where some degree of hydrologic management is considered beneficial. In these cases, either active or passive measures may be considered to control water levels, enhance vegetation, and achieve other objectives.

Additional information on the major types of enhancement and protection projects is provided here to assist readers in understanding subsequent discussions (including those in the basin plan appendices).

RESTORATION OF BARRIER ISLANDS

Louisiana's barrier islands form the outer edges of the estuarine system and provide important protection to the marshes of the Terrebonne and Barataria basins (and, to a lesser degree, those in the Breton and Pontchartrain basins). Their rapid loss (in some cases, disappearance is projected within 5 to 7 years) is considered a serious threat to the coastal ecosystem. A typical project to restore a barrier island involves dedicated dredging to increase island height and width; engineered structures which protect or enhance the island may also be considered. Projects to restore islands in the Isles Dernieres chain have been included on all three of the CWPPRA priority project lists submitted to date. Proposals have been advanced to restore the barrier islands on a comprehensive scale, using dredging sediment from Ship Shoal, an offshore sand body (Byrnes and Groat 1991). As with major sediment diversions, the scale of such a project would require a feasibility study.

FRESHWATER DIVERSIONS

Like sediment diversions, freshwater diversions bring natural fluvial processes into wetlands. Freshwater diversions usually take water from the upper part of a river's flow, using siphons or a levee cut fitted with gates. When water levels are high, some portion of the river flow moves through the structure and into wetlands on the other side of the levee, thereby mimicking on a small scale the historically widespread overbank flow process. Project benefits for these diversions primarily focus on the change effected on a salinity regime and the response of the existing biological resources to this change. However, because the fine silt and clay portions of riverine sediment loads are uniformly distributed throughout the flow, some accretion or wetland enhancement results as a secondary benefit of these projects.

Several freshwater diversions have already been built, and others are in the design or detailed planning stage under authorities other than the CWPPRA. Completed projects are prominent in the Breton Sound and Barataria basins and include the Whites Ditch, LaReussite, and West Point a la Hache siphons, and the recently completed, much larger gated structure at Caernarvon, with an 8,000 cfs capacity. Planned are the 30,000-cfs Bonnet Carré Diversion in the Pontchartrain Basin and the 10,650-cfs Davis Pond project in the Barataria Basin.

OUTFALL MANAGEMENT

Outfall management projects are used to realize the full benefits from existing or authorized freshwater diversions, including diversions such as pump station outfalls which normally are operated for water-level control rather than directly for wetlands benefit. The Caernarvon Outfall Management project, included on the 2nd Priority Project List, is an example of this project type. Management involves the control of water levels and direction of flow to increase dispersion and retention time of fresh water, nutrients, and some sediment in the marsh. Inducing overbank flow across the marsh surface, so that any sediments and nutrients present reach and are retained in the interior marsh areas, is also accomplished with this technique.

HYDROLOGIC RESTORATION

The term hydrologic restoration implies changing human-altered drainage patterns back toward natural drainage patterns. In the past, this approach has been directed largely at preventing saltwater intrusion, but increasingly it is seen as a way to correct marsh impoundment problems (Swenson and Turner 1987) in areas where soils become so waterlogged that vegetation becomes severely degraded (Mendelssohn and McKee 1988). The technique is especially appropriate in situations where the human impact on the drainage system is profound or where other types of solutions, such as regional sediment diversions, may not be practicable. The GIWW to Clovelly project from the first Priority Project List is an example of this technique applied over a large area.

At one end of the scale, specific hydrologic restoration projects can address the large navigation channels which connect the Gulf of Mexico with ports far inland, and which have allowed salt water to penetrate far into interior wetlands; major engineered structures (such as locks or gates) could rectify this problem, especially if benefits for hurricane protection can be incorporated to offset their high costs. At the other end of the spectrum, hydrologic restoration projects may simply involve small-scale measures to block off dredged channels, or the cutting of gaps in spoil banks created by dredging of canals.

HYDROLOGIC MANAGEMENT OF IMPOUNDMENTS

This technique involves active management of areas which have been impounded by levees or other structures. It is similar to the active marsh management techniques discussed below.

MARSH MANAGEMENT

This technique has been practiced in Louisiana for at least 50 years to manage primarily for waterfowl and furbearers, and more recently for wetland protection and restoration. A large number of marsh management projects have been permitted in the past ten years, and it has been estimated that nearly 500,000 acres are currently under management (Knudsen et al. 1985). The technique can result in the enclosure of areas of deteriorating marsh. Once contained, the water levels and hydrologic regime of the area are manipulated to promote the growth or restoration of desired vegetation and wildlife habitat. No matter how management is done, the exchange between the impounded area and the larger estuary becomes limited.

Passive management of water levels relies on weirs and other nonadjustable structures to maintain minimum water levels throughout the year. Active marsh management uses adjustable structures (such as variable crest weirs, gated culverts, and even pumps) and levees to alter water levels on a seasonal basis and to provide more overall control.

EROSION CONTROL

Some erosion control techniques are applied directly to a shore or bank, while others are in open water and aim to alter the waves and currents which cause erosion. Either way, consideration must be given to the natural forces which erode, transport, and deposit material. Among the project types which have been used in Louisiana are the following.

- Rock dikes, pile supported bulkheads, and earthen levees are the most common methods to protect fragile marsh soils from wave attack in coastal bays.

- A relatively new technique is to use a flexible concrete mat placed on top of an earth-fabric (geotextile); this approach is used on banks along relatively deep oil and gas canals where there is relatively high energy associated with vessel wakes. The approach illustrates how a project which reduces bank caving and associated wetland erosion can have additional benefits, in this case a reduced need for expensive channel maintenance.

- "Soft" protection to shorelines uses methods such as vegetative planting or the spraying of dredged materials to promote a root mat of healthy plants to stabilize the soil, decreasing loss due to wave erosion. The most commonly used species for erosion control in coastal Louisiana is saltmarsh cordgrass or oystergrass (*Spartina alterniflora*) which, once established, can withstand moderate wave energy and prolonged flooding. In some areas, temporary silt screens or wave dampening devices are used to protect the new plants until they become established, and protection of newly planted sprigs is sometimes necessary to prevent grazing by nutria. The Vegetative Plantings Demonstration Project from the first Priority Project List is an example of a project to determine which species of marsh grasses have such desirable characteristics as accelerated growth and resistance to prolonged flooding or high salinity.

- Segmented breakwaters have been constructed along the gulf shoreline of the western Chenier Plain, and more are proposed. These are intended to stabilize a shoreline by altering wave patterns and inducing deposition of coarse beach material behind the breakwater. Other types of structures (dikes, subsurface sills, or berms) have been suggested to achieve similar benefits.

OTHER MANAGEMENT TECHNIQUES

The toolbox of wetlands restoration techniques just discussed addresses most, but not all, of the causes of loss which were reviewed earlier in this report. Two examples illustrate other solutions available to the CWPPRA plan.

The first example is herbivore control. Grazing of marsh vegetation by nutria (an introduced species) and muskrat has contributed to the loss of Louisiana's coastal wetlands (Linscombe and Kinler 1984, Nyman et al. 1993). Pressure on these species from predators is light, and a decline in the worldwide fur market has eased pressure from trappers as well. Possible short-term control measures to be considered include fences, shooting, poisoning, and bounties. Longer-term solutions include actions which promote harvesting for food or fur. A second example is projects to enhance flotant marshes.

Finally, it is worth repeating that while construction of projects is the focus of the CWPPRA, it is not the only solution to problems of wetlands loss in coastal Louisiana. An important action is the development of appropriate regulatory controls, as part of the Louisiana Conservation Plan and as part of the environmental programs of federal, state, and local agencies.

SUMMARY

Louisiana's restoration ecologists and engineers have a wide range of restoration and enhancement techniques at their disposal, and as demonstration projects come on line this array of tools will increase. While some of the most promising tools--those which could achieve regional benefits--require detailed planning feasibility studies to delineate the best long-term, large-scale restoration projects for Louisiana's coastal wetlands, overall the prognosis is good that solutions exist, or will be found, to address the Louisiana coastal wetlands loss problem.

There are many issues involved in the implementation of any of these solutions; these issues are addressed in the Environmental Impact Statement.